University of Twente

Vanderlande Industries

Global Services

Redesigning after-sales services supply chain

Master Thesis Industrial Engineering and Management

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I

[Under uncertainty] there is no scientific basis on which to form any calculable probability whatever. We simply do not know. Nevertheless, the necessity for action and for decision compels us as practical men to do our best to overlook this awkward fact and to behave exactly as we should if we had behind us a good Benthamite calculation of a series of prospective advantages and disadvantages, each multiplied by its appropriate probability, waiting to be summed [Keynes, 1937].

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Preface

Dear reader,

Starting to look back at one my first internships, I happily watch back to what I've achieved until this specific moment of handing over this piece of work. Over the years I got the opportunity to work within wonderful multinationals like Vanderlande, Siemens or Sick Sensor Intelligence.

Primary I want to thank my parents, who always directed me in towards right direction during difficult life choices. Especially when I was still young and growing up. I want to thank heartily Matthieu van der Heijden and Leo van der Wegen who, next to educating me various sub-disciplines of industrial engineering, supervised my master thesis and learned me how to write a decent paper. I want to specially thank Frank van Schijndel and Stefan van Venrooij for giving me the opportunity to work within Vanderlande and learning me all ins and outs of the interesting field of supply chain management. Last but not least I want to thank Maarten Schaaf, who welcomed me directly from the start within Vanderlande Spare Parts and teached me decent grammar.

During my master's degree at the University of Twente, I acquired legitimate knowledge about production & logistics management. Additionally, I captured a brighter orientation on the world because of the given chance to do an exchange program at UNSW during my master's degree.

Therefore I want to remark that I recognize my time at the University of Twente as one of the best. I admired the way how teachers thought me several fields of industrial engineering in a supportive manner of tutoring. Furthermore I got to know many new friends during these two years.

By all this, I hope to make a difference in gaining control and reducing environmental impact in our ever-changing world. This, by continue improving systems involving various crucial resources like employment, materials, energy and knowledge.

Enjoy reading!

Thijs Mentink

Utrecht, November 28, 2018

Summary

This research focuses on a feasibility study for opening a warehouse facility in the Asia-Pacific region.

Problem description
Vanderlande is currently facing strong growth, amongst others in the Asia-Pacific region. The mission of Vanderlande is improving the competitiveness of customers through value-added logistic process automation. With controlling the supply of spare parts in the Asia-Pacific region via the central warehouse in Best the question arises if Vanderlande succeeds in this mission for their customers in this region.

This raises the question whether it makes sense to open a regional warehouse for spare parts to serve the Asia-Pacific region, now or in the future. And if it makes sense, where should this warehouse be located?

Approach
We follow the Managerial Problem Solving Method of the book "solving managerial problems systematically" of [Heerkens, 2017] for setting up the framework of our research paper. Besides we use the network design decisions framework from [Chopra and Meindl, 2013] to add important elements to our research.

The approach for achieving results is phased in multiple research steps. First we provide an analysis of the current situation, this will be used as input for the solution approaches. The literature review functions as purpose to generate models that will give direction to our solution approaches.

With relevant literate and input parameters from analysis of current systems, we will be able to determine alternative solutions for setting up the regional warehouse. By using Multi Criteria Decision Analysis (MCDA) we will find the optimal alternative solution.

Based on various findings throughout this study, we will provide recommendations to Vanderlande.

Results
First of all we were able to estimate (future) costs for setting up a warehouse facility to serve the Asia-Pacific region. We therefore built an optimization model. Decisions on warehouse locations are based on an interaction between various criteria, we were able to make our decisions by solving a MCDA problem.

Key criteria in our MCDA model are costs, potential sales in Asia-Pacific countries, Customer order Lead-time, political- and exchange rate stabilities, Criticality parts and Dangerous goods.

From our model we conclude that motivations on location decisions should come forward from benefits like for example timely delivery. Based on abilities of timely delivery Dangerous goods and Criticality parts to Vanderlande's Asia-Pacific customer sites, it makes sense to open a new regional warehouse. In general Customer order Lead-time towards Asia-Pacific customers is demonstrated to be shortest from a new regional warehouse facility in Australia.

Customer order Lead-time of spare parts is a critical factor for Vanderlande's customer's system uptime.

Based of conclusions about order-fulfilment, we should locate our regional warehouse in Melbourne. More than 80% Order-lines from Stocked items will be delivered to Australian Warehousing Parcel and Postal (WP&P) customers. Most critical and dangerous items that should be kept on stock from our inventory advise, are intended for Australian WP&P market. When Vanderlande would open a this warehouse, Vanderlande has to count for around €53.726 of *inventory value* on stock for serving Asia-Pacific demand.

Based on results from our MCDA model, we conclude that the best alternative is opening a Distribution center in Melbourne to serve all Asia-Pacific replenishment demand. Next to fulfilling orders from Stocked items, this warehouse should function as Cross docking location for all Asia-Pacific demand. To begin, Vanderlande Spare Parts should fulfil all Australian WP&P orders from this regional warehouse facility.

Opening a Distribution center in Melbourne to serve Asia-Pacific customer sites will cost approximately €11.577 per year. When Vanderlande prefers to keep all critical and dangerous items on stock, one could

expect higher (future) inventory and warehousing costs. Furthermore if Vanderlande would source in the same country as the country location of the regional warehouse, cost reduction might become realistic.

The strongest growth among all different countries and industries is growth from Australian WP&P customers. This motivates that *based on future sales it is beneficial to locate in Melbourne, Australia.*

Taking into account growth path we will expect increasing future operating costs for this new facility. However, additional supply chain costs will not become significant (€ 17.419 in 2022).

Recommendations
Various findings have been discovered during the execution of this study. Summarized, we represent the key recommendations towards the global spare parts department.

- Since establishment climate of western countries will give benefits on import costs and emerging economies will result in low warehousing costs, perspectives on (future) costs support that our location decision should come forward on beneficial factors like e.g. customer's systems uptime only.
- Vanderlande Spare Parts should develop an explicit competitive strategy. It is difficult, or maybe even impossible, to make network distribution decisions without setting strategic supply chain objectives from for example trade-offs between service and costs. This explains divergent views from managers on utility of this new warehouse facility in weighting benefits and costs for our MCDA model.
- However, setting up the regional warehouse will increase Vanderlande its ability to provide customer sites timely with spare parts. Therefore Vanderlande will improve its competencies to help Asia-Pacific customers sites increasing their uptime. This could lead to more project sales in this region.
- Almost all Order-lines fulfilled from Stocked items will be delivered to Australian WP&P customer sites. Besides most critical and dangerous items that Vanderlande should keep on stock by our inventory advise, are intended for Australian WP&P market. Based on shortest Customer order Lead-time and customer's systems uptime, we therefore advise to set up the regional warehouse in Melbourne.
- To begin, Vanderlande should start fulfilling all Australian WP&P orders from the new warehouse in Melbourne. After appropriate implementation, we advise to serve all APAC demand from this facility.
- Furthermore, not even taking into account current Packages sales, we noticed strongest growth among Australian WP&P sites. This also motivates why Vanderlande should locate in Melbourne, Australia.

Glossary

Customer centers The representing business entity for certain division in a specific set of countries pp. 2, 49

Consignment stock Consignment stock is stock legally owned by one party but held by another; meaning that the risk and rewards regarding to the said stock remains with the first party while the second party is responsible for distribution or retail operations [Valentinia and Zavanella, 2015] p. 40

Criticality Criticality expresses the importance of a part in case of system failure [van den Bosch, 2017] pp. VI, XVI, 19, 35, 41, 42, 45, 50

Cross docking Cross-docking is unloading of materials from an incoming vehicles and loading these materials directly into outbound vehicles with little or no storage in between [Wikipedia, 2009] pp. VI, 2, 8, 32, 40, 50, 72

Cycle service level Specified probability of no stockout per replenishment cycle pp. 16, 20, 22

Dangerous goods Some spare parts are considered as dangerous goods; carriers of Vanderlande do not accept these type of goods for their air transportation pp. VI, XVI, 18, 41, 45, 50

DHL International carrier company for the shipment of parcels and contract logistics pp. 2, 12–14, 30, 48, 51, 61, 65

Distribution center The term distribution centre is used to explain the specific characteristics of a warehouse facility that consolidates orders for customer sites. Next to fulfilling orders from stock this facility also delivers orders to customer sites by e.g. example cross docking pp. VI, 2, 5, 29, 30, 32, 36–38, 40, 45, 47, 50, 72, 77–83, 88, 90, 92

Fast movers Frequent demand occurences pp. 3, 16, 20, 23, 28, 33, 34, 61

Fill rate Specified fraction of demand to be satisfied routinely from inventory pp. 22, 34, 49

Flow intensities Flow intensities refers to number of pieces sold *or* purchased from different SKU's pp. XV, XVI, 8, 10, 11, 18, 19, 30, 41, 61

GDP per capita Gross domestic product per capita pp. 13, 36, 46

Customer order Lead-time Time in days to deliver orders to customer pp. VI, VII, XVI, 3, 6, 17, 18, 25, 29, 32, 40–42, 44, 45, 49–51, 61

Logistical Support Logistical Support is responeseble for order dispatchment to customer sites pp. 1, 2, 6, 8, 16, 18, 49

Order-lines An order line represents a part of an order on a bill. An order line can be made up of one item or multiples of an item [Inc, 2018] pp. VI, VII, 10, 13, 19, 29, 36, 39–41, 44, 45, 49–51, 84

Packages A spare parts package is a package of spare parts that is composed for a client before new system is taken over for use [Kupinski, 2018] pp. VII, XV, 5, 8, 11, 17–19, 33, 41, 46, 49, 51, 61

Replenishment parts Replenishment parts are result of a direct order from a client during the opration time of thier systems [Kupinski, 2018] pp. XV, 5, 8, 10, 11, 15, 17, 40, 46, 49

Slim4 Slim4 is Inventory Optimization Software for service level-based Forecasts and Inventory Management [Slimstock, 2018] pp. 15, 16

Slow movers Low average demand per period pp. 16, 20, 23, 28, 33–35

Stock-location Warehouse facility that only delivers stocked items to customer sites pp. XVI, 2, 5, 29–32, 36–38, 77–83

Stocked items Items considerd to be kept on stock in warehouse by for example logistical parameters pp. VI, VII, 2, 7, 15, 29–33, 39, 40, 42, 44, 50, 51, 65, 72, 73, 86

Supplier Lead-time Time in days to receive orders from suppliers pp. 10, 15, 22, 23, 34, 49

Visa Global Logistics Public warehouse in Australia pp. 13, 48

Abbreviations

AHP Analytical hierarchy process pp. XIII–XVI, 26–29, 42–46, 50, 51, 87, 88, 90, 92

AMER North Central and South America pp. XIV–XVI, 2, 8–11, 31–40, 45, 58, 59, 73, 75, 77, 84

APAC Asia-Pacific pp. VII, XIV–XVI, 2, 8–11, 17, 30–37, 39–41, 44, 45, 47–49, 51, 58, 59, 75–79, 82–84

CEO Chief Executive Officer p. 1

CI Consistancy index pp. 27, 43, 44, 88, 90, 92

CODP Customer order decoopling point pp. 9, 10, 31, 35

Dc Import duties pp. 37, 38, 47, 78–81

DG Dangerous goods pp. 18, 41

EMEA Europe Middle-East and Africa pp. XIV–XVI, 2, 8–10, 19, 30–40, 45, 46, 58, 59, 73, 75, 77, 84

FSL Forwarded stock location pp. 2, 44

FTE Fulltime-equivalent p. 12

GDC Global distribution center pp. XV, 2, 11, 18

GDP Gross domestic product p. 13

GPRI Global Political Risk Index p. 18

Ic Inventory costs pp. 37, 38, 47, 77–81

IT Information Technology p. 1

MCDA Multiple-criteria decision analysis pp. VI, VII, 5–7, 21, 26–29, 37, 40, 42, 46, 50

MPSM Managerial Problem Solving Method p. 4

P&L Profit and Loss p. 1

PO Purchase order p. 12

R&D Research and development p. 1

RDC Regional distribution center pp. 2, 44

Repl. parts Replenishment parts pp. XV, XVI, 18, 33, 39, 41, 86

RQ Research question pp. 4–6, 8, 9, 12, 14–16, 19, 21, 23, 25, 27, 28, 40, 41, 45

RW Regional warehouse pp. XIV–XVI, 2, 9, 13, 29–37, 39, 40, 47, 59, 61, 73–77, 84

Tc Transportation costs pp. 37, 38, 47, 77–81

USA United Stades of America pp. 2, 3

Wc Warehousing costs pp. 37, 38, 47, 77–81

WP&P Warehousing parcel and postal division pp. VI, VII, 1, 19, 29, 37, 39–42, 44, 45, 48–51, 88, 90, 92

Symbols

A Ordering costs pp. 16, 23, 26

A N*n pairwise comparison matrix pp. 26, 27, 43, 87, 89, 91

a_i X coordinate of the location of customer site i p. 21

A_{norm} Normalized n*n pairwise comparison matrix pp. 27, 43, 87, 89, 91

b_i Y coordinate of the location of customer site i p. 21

cv^2 Squered coefficient of variation p. 22

D Yearly demand pp. 23, 34, 35

ds Average demand sizes at demand events pp. 22, 33, 34

EOQ Economic order quantity p. 23

IP Inventory position pp. 16, 22

L Supplier Lead-time p. 22

δ_i Latitude pp. 21, 30

φ_i Longitude pp. 21, 30

p Average number of periods between demand events pp. 22, 33, 34

$P1$ Cycle service level pp. 16, 22

$P2$ Fill rate pp. 22, 23, 33–35, 49

P_i Coordinates of the location of customer site i p. 21

Q Order size pp. 22, 23, 28, 34, 35

r Carrying charge pp. 16, 23

r_e Earth radius (in km; 6367) pp. 21, 30

s Reorder point pp. 16, 22, 23, 28, 34, 35

SS Safety stock pp. 22, 34

T Mean repair shop throughput time (in year) pp. 23, 34, 35

v Item costs p. 23

w_i Weight of objective i pp. 26, 27, 43

x X coordinate of the location of new warehousing facility p. 21

X Coordinates of the location of new warehousing facility p. 21

y Y coordinate of the location of new warehousing facility p. 21

Contents

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1 Introduction

The first chapter contains the introduction. We will provide the structure of our research.

1.1 Description of Company

1.1.1 Vanderlande

Vanderlande is global market leader for value-added logistic process automation at airports, and in the parcel market. The company is also a leading supplier of process automation solutions for warehouses. Its systems are active in 600 airports including 13 of the world's top 20. In addition, many of the largest global e-commerce players and distribution firms have confidence in Vanderlande's efficient and reliable solutions. The company focuses on the optimization of its customers' business processes and competitive positions. Established in 1949, Vanderlande has more than 5,000 employees, all committed to moving its customers' businesses forward at diverse locations on every continent. With a consistently increasing turnover of more than 1.1 billion euros, it has established a global reputation over the past six decades as a reliable partner for value-added logistic process automation [Vanderlande, 2016].

The mission statement of Vanderlande acknowledges that: *"We improve the competitiveness of our customers through value-added logistic process automation."* [Vanderlande, 2016].

The Vanderlande organisational structure can be considered as divisional staff type of organisation. Within Vanderlande there are two main divisions, namely: Airports, Warehouse Parcel and Postal (WP&P). These divisions are P&L responsible for their part within the total Vanderlande organization. Next to these two divisions Vanderlande has various staff (support) departments, we can subdivide these in R&D, Operations, Finance and Human Resources.

Within Vanderlande, Global Services functions as separate business entity and is supporting the 2 divisions. Global Services reports directly to the CEO. As example, baggage handling belongs to the division Airports. When a problem occurs with the baggage transportation system at one of the customer sites, Vanderlande Spare Parts will supply the spare part in order to restore the system in its original state.

1.1.2 Global Services and Global Spare Parts

Next to initial supply, Vanderlande facilitates maintenance of systems by a.o. supplying spare part packages, and offering site based services by own personnel at for example Airports. Global Services is responsible for delivering the service proposition.

The service proposition of Vanderlande comprises 3 types of partnerships: asset services, logistic services and business services. Asset services refers to the cases in which Vanderlande supports and maintains the complete system including software, IT and controls. The supporting solution consists of a 24/7 hotline, periodic inspections, access to spare parts and education of the customer's own maintenance technicians. In logistic services, Vanderlande operates and optimises the customer's logistical process. Furthermore, the service proposition business services is chosen when the customer wants Vanderlande to consult on projects [van Schijndel et al., 2016].

This sentence is removed for publication. Global Services generates its own sales, designs & builds systems and operates & maintains its own business entity.

Vanderlande Spare Parts consists of three main teams, Logistical Support, Product & Marketing Support and Sales Support. Logistical Support is managed by Stefan van Venrooij. In Logistical Support the spare parts are ordered from suppliers and dispatched to customer sites. Product & Marketing Support is responsible for content and lifecycle management. This sentence is removed for publication.

The study "A study on which Services to offer in the year 2020" of Frank van Schijndel provided directions to new services that Vanderlande Spare Parts needs to offer in 2020. The key recommendation formed building a business case consisting two main parts:
1. Marketing study.
2. Service Network Design study [van Schijndel, 2016].

In an appropriate way, we will focus on the second part of this main business case. The Service Network Design study should give answer to questions on how many warehouses would be needed? Which items would have to be stored where? And how much would that cost? Therefore the model to be designed should be flexible so Vanderlande can try multiple scenarios [van Schijndel, 2016].

Since Stef van den Bosch already performed past research on opening warehouses in the EMEA region and there is already a regional warehouse for serving AMER demand, we will only focus an Service Network Design study for the Asia-Pacific demand (and APAC supply).

1.1.3 Spare part order fulfilment process

Logistical Support manages spare part order fulfilment on a global basis. Therefore Logistical Support operates a warehouse in the Netherlands near the Vanderlande headquarters in Veghel.

The spare part replenishment process is important to customers because capabilities of delivering spare parts timely at the customer sites improves the customer's ability to operate their normal business activities.

Vanderlande uses two warehouses and a Stock-location to deliver spare parts to customer sites among the world, the central warehouse is outsourced to DHL (public warehouse).

Next to the central warehouse in Best Vanderlande operates a regional warehouse in Acworth, America and a forwarded stock location in Russia. The regional warehouse in America is not directed by the global spare parts department. We briefly list the functional warehouses and corresponding locations:

- GDC (11002): Global Distribution Center (GDC) or "central warehouse". Best - The Netherlands
- RDC (60002): Regional Distribution Center RDC or "regional warehouse (RW)". Acworth - USA
- FSL (34002): Forwarded Stock Location FSL or "Stock-location". Moscow - Russia

Each of the central- and regional warehouses serves its own customers and is responsible for its own dedicated inventory management. The regional warehouse (2) in the USA often replenishes via the central warehouse in Best. The forwarded stock location (3) is managed by the logistical support team in Veghel.

In our study it is necessary to adopt definition that will be used continuously throughout this whole research. Warehouse will be used as a general term, however when needed the term Distribution center is used to explain the specific characteristics of a facility [Colliander and Tjellander, 2013] that consolidates all (or complete) orders for customer sites. Next to fulfilling orders from stock, Vanderlande also fulfils orders to customer sites by e.g. example Cross docking from this specific type of warehouse facility. In case of a Stock-location, we refer to a facility that only delivers Stocked items to customer sites.

Spare part replenishments in the Asia-Pacific region are regularly managed by Logistical Support. However, Customer centers occasionally fulfil orders without any involvement of the logistics support team. Consequently this results that some shipments are sent directly from suppliers to customer sites.

In this study we are going to determine the benefits and costs of setting up a regional warehouse in the Asia-Pacific region and we will provide a feasibility study for alternatives decisions of managing parts supply in the future. Further explanation about how we explore this study, will be described in this first chapter.

1.2 Research plan

1.2.1 Problem description

Vanderlande is currently facing a strong growth, amongst others in the Asia-Pacific region. The mission of Vanderlande is to improve the competitiveness of its customers through value-added logistic process automation. By controlling the supply of spare parts in the Asia-Pacific region via the central warehouse in Best, the question arises if Vanderlande succeeds in this mission for their customers in this region.

Availability of spare parts is important since downtime may have serious consequences. For example, downtime of a baggage handling system at an airport leads to baggage that misses its flight, which leads to significant costs. Therefore, spare parts needed for quick system recovery are typically stored at the customer sites. These spare part inventories are replenished upon request of the customer.

While Vanderlande Spare Parts currently maintains one central-, and one regional- warehouse (in the USA) to serve all customer sites over the world, the question arises whether this is optimal. Therefore we need to analyse the current situation of spare part replenishment and consider alternatives, we could for example keep operating as today or set up a new regional warehouse (considering strong growth in the Asia-Pacific region).

As stated, Vanderlande is currently facing a strong growth in the Asia-Pacific region. This raises the question whether it makes sense to open a regional warehouse for spare parts to serve the Asia-Pacific region. And if it makes sense, where should this warehouse be located (China or somewhere else in the region)? And if it would appear to be too early to open a warehouse in that region: what is the break-even point in spare part volume for which such a warehouse would be profitable? Possible advantages of having a regional warehouse include:

- Resupply of spare part inventories at customer sites as well as emergency supply in case of system downtime and lack of spare parts can be performed faster (Asia-Pacific region serve Asia-Pacific customers).
- Increasingly, components are produced in China. In the current situation this means that a part of the spare part flow is first moved from Chinese suppliers to the warehouse in Best, and next back to the customers in Asia-Pacific. A regional warehouse could therefore reduce transportation costs (Asia-Pacific warehouse serve Asia-Pacific customers instead of central warehouse serve Asia-Pacific customers).
- With increasing spare part sourcing in China an optimal place for setting up a warehouse to serve customer sites over the world would probably be in the Asia-Pacific region, this will safe transportation costs and order Customer order Lead-time.
- A certain fraction of spare part inventories can be centralized (i.e., moved from the customer sites to the regional warehouse), which may lead to an inventory reduction by profiting from a risk pooling effect.
- With certain parts (especially Fast movers) currently sourced locally in for example China and delivered to customers in the Asia-Pacific region again directly it might become profitable to keep this part on stock when opening the regional warehouse.

Of course, there are also drawbacks, such as the costs of establishing and running a warehouse in Asia-Pacific, and extra handling of parts. Also fiscal regulations, in for example, China can potentially cause unnecessary costs with a regional warehouse in the Asia-Pacific region.

Last but not least, we have to consider qualitative opportunities of this possible new regional warehouse, i.e. understanding impacts of building a new regional warehouse in terms of, for example, the possibility of an increasing market share in spare parts, because of becoming a more local partner with an enhanced connectivity to specific regions. Next to opportunities, there are always risks involved, like, for example, geography local political environments. We have to take all these considerations into account to come with objective conclusions to the stated problem.

1.2.2 Research objective

To determine the (future) benefits, potential, and costs for setting up a new regional warehouse to serve the Asia Pacific region, we have to build a model to quantify the benefits and costs of a regional warehouse in the Asia-Pacific region. Therefore we need to optimize the inventory allocation and find the optimum location under multiple scenarios. Using this model we will be able to show whether a regional warehouse in Asia-Pacific is profitable at this point in time. In case the answer is negative, we should show when a regional warehouse could become profitable, taking into account a growth path for the installed base in Asia-Pacific. Next to this we have to consider benefits and risks that will arise with setting up a warehouse within the Asia-Pacific region.

1.2.3 Research questions

In our research we will follow the Managerial Problem Solving Method (MPSM), described in the book "Solving managerial problems systematically" of Hans Heerkens. This book follows the method of General Business Problem Solving, which provides instructions to systematically solve problems step by step [Heerkens, 2017]. The network design decisions framework from the book "Supply Chain Management", by S.Chopra and P. Meindl is used to add relevant elements about network design to our research.

Given our problem statement and research objective, we define the main question of our research study as: *"Does it make sense to open a regional warehouse for spare parts to serve the Asia-Pacific region. And if it makes sense, where should this warehouse be located (China or somewhere else in the region)? And if it would appear to be to early too open a warehouse in that region: what is the break-even point in spare part volume for which such a warehouse would be profitable?"*

I. Analysis of current order fulfilment, corresponding costs and growth path in Asia-Pacific
First we have to understand the current order fulfilment process before we can determine solutions to the earlier described problem description of this research paper. Therefore we need to understand historical replenishment flows from order data and inventory management systems. We will have to find input parameters for our solution approaches. For this analysis we formulate the following research questions (RQs):
1. How do the spare parts flow from suppliers via the central warehouse to the customers in the Asia-Pacific region? And how do they flow from between suppliers in the Asia-Pacific region to the central warehouse and eventually the rest of the world?
2. What partition of the spare parts flows (in and out) are beneficial to manage from the regional Asia-Pacific region warehouse?
3. In what way is the global spare parts department currently managing inventory?
4. Which costs are involved with the current way of managing spares for the customers of Vanderlande? (i.e. transportation costs, warehousing costs, inventory costs and import costs)
5. What are other (beneficial) factors of Vanderlande that should be considered when setting up a new regional Asia-Pacific warehouse?
6. How could we interpret the potential of future Asia-Pacific spare parts sales?

II. Models from literature to determine (future) benefits and costs for setting up a new warehouse facility in the Asia-Pacific region
After identifying historical replenishment flow patterns, input parameters for warehousing facility costs and current inventory management systems, we have to find models from literature to determine solution approaches for our research problem. To find these solution approaches we formulate the following RQs:
7. What solution approaches will solve our research problem?
8. Which models from literature are available to determine an optimal location for the new regional warehouse? And when locating this Asia-Pacific warehouse, which models can be used for determining an optimal stock allocation?
9. What qualitative (dis)benefits can we demonstrate from literature for setting up this regional warehouse?

III. Apply solution approaches to determine (future) costs and benefits for different alternatives of Asia Pacific order fulfilment
With relevant models from literature available we are able determine solution approaches. From here we can conclude (future) benefits and costs of different alternatives. We formulate the following RQs:
10. What (beneficial) matters will come forward on locating a new warehouse in the Asia-Pacific region?
11. How could we improve optimal sourcing for customer sites considering different alternatives and growth path in the Asia-Pacific region?

IV. Recommendation
In this last section of this research paper we will give recommendations in terms of a choices and consequences.

In appendix A1 we represent the illustration of the research framework, the outlined RQs are in line with this framework.

1.2.4 Research scope

To define the research scope we have to determine what exactly to explore in this study. Within this study we will determine the benefits and costs for setting up a new warehouse facility to serve the Asia Pacific region. Therefore we need to analyse multiple future scenarios for locating this warehouse.

We only consider Replenishment parts demand and not Packages demand (further definition in appendix A5) to determine benefits and costs, because replenishment demand is returning demand of spare parts from customer sites. However initial Packages sales could, of course, develop in future replenishment sales.

Since the Asia-Pacific replenishment sales market is not relevant enough for locating multiple regional warehouses, we will only generate scenario's for opening one location. We will take into account different possible warehouse functions. Namely only consider the proposed warehouse facility as Stock-location or the situation of also consolidating orders from this warehouse (warehouse functions as full Distribution center).

Because we will also take into account multiple non-cost arguments for finding the optimum warehouse location, the problem represents characteristics of a multiple-criteria decision analysis MCDA problem.

In order to obtain a representative reflection to the real world situation we will take all different items, suppliers and customer sites into account. Because of the design of the current Vanderlande Spare Parts supply chain we will only consider one or a combination of the two following network design options, namely:

- Manufacturer storage with direct shipping, where product is shipped directly from the manufacturer to the end customer.
- Distribution storage with carrier delivery, inventory is not held by manufacturers at the factories, but is held by distributors in intermediate warehouses and carriers are used to transport products from the intermediate location to the final customer [Chopra and Meindl, 2013].

We will have to consider strategic benefits and risks that will arise if setting up this new regional warehouse, this will require a more qualitative study.

Besides we will have to consider the fiscal political climate within determining the optimal warehouse location. Moreover, we have to take into account rent expenses, valuta risks and for example labour rates with finding an optimum location for this regional warehouse.

Nevertheless we also determine limitations for this study. Given Vanderlande currently operates a forward stock location in Moscow and one could expect it could be beneficial to manage a partition of the Asia-Pacific region flow (i.e. suppliers and/or customers) from this stock location. But since this forward stock location only exists because of political reasons, we will not consider managing spares from this stock location.

In this research we will ignore reverse logistics of defect spare parts from customer sites back to a central- or regional warehouse warehouse, as Vanderlande counts most defective parts as scrap.

Many factors will have an impact on location decisions. The relative importance of these factors depends on whether the scope of a particular location problem is international, national, or statewide. For example, if we are trying to determine the location of a warehouse in a foreign country, factors such as political stability, foreign exchange rates, business climate, duties, and taxes play a role [Farahani et al., 2009]. We will take all these factors into account in providing Vanderlande with well considered recommendations.

We will only determine solution approaches based on a single echelon model. We will model the problem as if the proposed warehouse facility replenishes directly from suppliers *and not* by the central warehouse.

1.2.5 Research approach

As stated in the previous section we follow the Managerial Problem Solving Method of dr. Hans Heerkens as framework of this research. This section explains our approach for answering the RQs of this study.

I. Analysis of current order fulfilment, corresponding costs, growth path and inventory software
1. How do the spare parts flow from suppliers via the central warehouse to the customers in the Asia-Pacific region? And how do they flow from between suppliers in the Asia-Pacific region to the central warehouse and eventually the rest of the world?
2. What partition of the spare parts flows (in and out) are beneficial to manage from the regional Asia-Pacific region warehouse?
Vanderlande takes record of historical transaction data, with this dataset we are able to determine spare part flow between suppliers, warehouse facilities and customer sites. From here we can decompose different flow and eventually conclude which partition of the spare parts flow should be considered as beneficial to be managed from an Asia-Pacific warehouse facility. We will provide scenarios using this same dataset.

3. In which way is the global spare parts department currently managing inventory?
First of all we can determine the currently used inventory models by analysing the current process of making a purchase order. From here we can analyse the software used for Logistical Support's inventory management system. We will analyse current inventory policies, input parameters and Lead-times.

4. Which costs are involved with the current way of managing spares for the customers of Vanderlande? (i.e. transportation costs, warehousing costs, inventory costs and import costs)
In Vanderlande's spare part business, transportation costs are calculated by weight and not by volume. With transported weight of relevant flow, together with rates for inbound and outbound shipments, we are able determine transportation costs. We will determine warehousing costs by finding costs parameters for operating small public warehouses. Inventory costs should come forward on analysing inventory systems.

5. What are other (beneficial) factors of Vanderlande that should be considered when setting up a new regional Asia-Pacific warehouse?
We will analyse (dis)benefits by determining various factors like supply chain strategy, exchange rate stabilities, political risk and for example Customer order Lead-time. Together with import costs, exchange rates will represent the macroeconomic factors that will be considered in decisions on whether and where to locate the regional warehouse facility.

6. How could we interpret the potential of future Asia-Pacific spare parts sales?
Growth path can be determined by analysing growth in installed base and historical spare parts sales.

II. Models from literature to determine (future) benefits and costs for setting up a new warehouse facility in the Asia-Pacific region
7. What solution approaches will solve our research problem?
The problem will be solved using an interaction between scenario and inventory modelling.
8. Which models from literature are available to determine an optimal location for the new regional warehouse? And when locating this Asia-Pacific warehouse, which models can be used for determining an optimal stock allocation?
This part contains the literature review, relevant literature will give the direction to our solution approaches. There are several theoretical sources available for analysing scenario's, like for example multiple-criteria decision analysis (MCDA). This also counts for determining an inventory allocation for the alternatives.

9. What qualitative (dis)benefits can we demonstrate from literature for setting up this regional warehouse?
With the analysis of possible effects concerned with opening a regional warehouses from various literature from books or papers, we are able to find qualitative motivations.

III. Apply solution approaches to determine (future) costs and benefits for different alternatives of Asia Pacific order fulfilment
10. What qualitative matters will come forward on locating a new warehouse in the Asia-Pacific region?
Provided qualitative (dis)benefits from literature will enable us to give proven effects of practice that would support or withhold opening a regional Asia-Pacific warehouse.

11. How could we improve optimal sourcing for customer sites considering different alternatives and growth path in the Asia-Pacific region?
With historical transaction data of spare parts and relevant literature we will be able to determine the optimal location for setting up the new regional warehouse under several alternatives.

Our problem represents characteristics of a MCDA problem. We will take into account various factors in our decision analysis and, of course, verify the most promising models. We will have to determine inventory allocation to provide the required inventory for this proposed warehouse facility.

Determining an optimum location is an interaction between benefits from for example our inventory models and costs like e.g. transportation and warehousing costs. When Stocked items are only replenished from a certain country, this is a strong reason to locate within this same country.

We will allow different alternatives and possible warehousing functions in making decisions for the new warehouse facility. Besides we will provide (future) benefits and costs considering growth path. This type of reasoning should form strong ground for our recommendations to Vanderlande.

IV. Recommendation
With the results from the solution approaches we will provide the global spare parts department with recommendations. These solution approaches will come forward from multiple scenario's, built on determining all relevant cost components, an optimum inventory allocation and a literature review on qualitative benefits for setting up this regional warehouse.

1.2.6 Structure of research paper

This research will be structured as follows. The first chapter of this study consists the research plan, this functions as research proposal. In chapter 2 we execute analysis of the current situation, this will simultaneously be used as input for the solution approaches to be developed in further stage. In this part we identify the spare parts order fulfilment process by using historical transaction data.

Chapter 3 contains the literature study. The literature review functions as purpose to generate models that will give direction to our solution approaches. With relevant literate and input parameters from analysis of current systems in chapter 2, we will be able to determine alternative solutions for setting up the regional warehouse. By using Multi Criteria Decision Analysis (MCDA), we will find the optimal solution.

With our solution approaches in chapter 4, and based on various findings throughout this study, we will provide recommendations to Vanderlande.

If we translate this to the given phases of our research, as provided in our research approach, I. will consist the research plan, II. the current analysis, III. the literature review and IV. will contain the solution approaches and the implementation plan. Conclusions and recommendations will also form a part of phase IV.

2 Analysis of current situation

We have to gain understanding of the current order fulfilment process before we can determine solution approaches to the problem description of this research. Therefore we will analyse current spare part flows, worldwide shipping, warehousing management systems and inventory management systems.

2.1 Spare parts flows

To eventually determine an optimum location for the new regional warehouse we need to study Flow intensities. Flow intensities refers to number of pieces sold or purchased among all different items. In order to solve our initial stated problem we require information about flow that may be managed by this warehouse.

2.1.1 Worldwide spare part flows

Vanderlande Spare Parts fulfils orders from a specific range of demand-types (usually Replenishment parts or Packages) from the central warehouse in Best. By use of the *central warehouse*, Logistical Support is most of times (partly) responsible for delivering orders to all installed bases over the world. Differences between Replenishment parts and Packages are described in appendix A5.

This has the consequence that for example when customer sites in Asia-Pacific orders certain *stock keeping spare parts*, Logistical Support will replenish these parts from their different suppliers among the world. In addition, Vanderlande has several, and a growing number of, suppliers in this Asia-Pacific region. Resulting that occasionally, by the central warehouse, Logistical Support orders spare parts from e.g. China to eventually deliver it back to surrounding countries of China.

Furthermore, the central warehouse functions as *Cross docking location* for customer orders. In this situation a spare part is handled by the warehouse, but not necessarily kept on stock.

In contrast of above mentioned type of flows, where Vanderlande stores a specific range of parts and consolidates orders in the central- or regional warehouse; in some cases Vanderlande also delivers parts from supplier *directly* to customer sites (without handling in a central- or regional warehouse).

In Figure 1 below we show how goods move to and from other parts of the world. The descriptions of these flows are provided in Table 1. References to elements like e.g. suppliers, customers or warehouses are given in this illustration as well. To be clear, suppliers and customers of regions are aggregated and added on one certain spot. In appendix A4 we added a list with Asia-Pacific customer sites and worldwide suppliers.

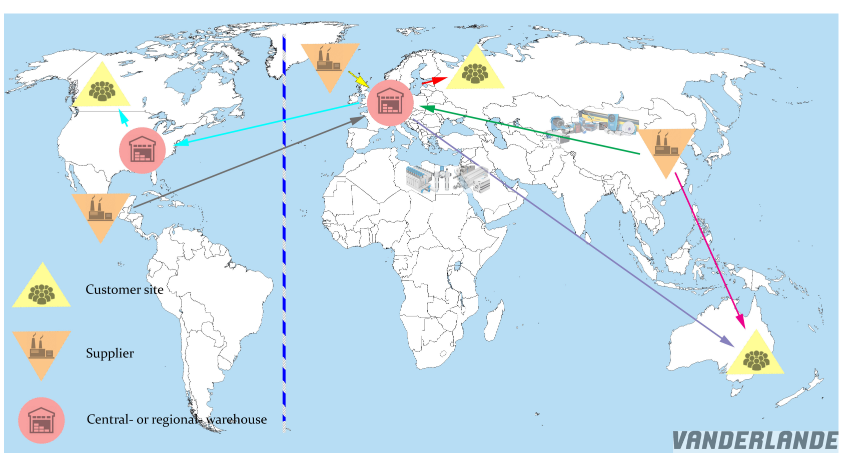

Figure 1: Current spare part flow

In resolution to the first RQ *"How do the spare parts flow from suppliers via the central warehouse to the customers in the Asia-Pacific region?"* we are able to globally summarize the nine main spare part flows in the table below.

FlowNum	Arrow	Color	Decomposed flow	Inbound/Outbound	Direct or via central warehouse
1	→	Green	APAC supplier to central warehouse	Inbound	Central warehouse in Best
2	→	Gray	AMER supplier to central warehouse	Inbound	Central warehouse in Best
3	→	Yellow	EMEA supplier to central warehouse	Inbound	Central warehouse in Best
4	→	Purple	Central warehouse to APAC customer	Outbound	Central warehouse in Best
5	→	Blue	Central warehouse to AMER customer	Outbound	Central warehouse in Best
6	→	Red	Central warehouse to EMEA customer	Outbound	Central warehouse in Best
7	→	Pink	APAC supplier to APAC customer	Inbound/Outbound	Direct delivery from suppliers
8			EMEA supplier to APAC customer	Inbound/Outbound	Direct delivery from suppliers
9			AMER supplier to APAC customer	Inbound/Outbound	Direct delivery from suppliers

Table 1: Current spares flow

Since the flows between AMER (i.e. supplier and/customer) and the Asia-Pacific region are relatively insignificant, we separated this part of the world-map by a blue dotted line.

2.1.2 Asia-Pacific spare part flows

To determine which flows Vanderlande should allocate to the new warehouse facility, we need to decompose the partition of spare parts flow that could be managed from the proposed regional warehouse. Therefore, we will first provide the partition of flows that could be assigned to this new regional warehouse.

To illustrate one possible way of future parts delivery from stock or consolidation of orders when opening a regional Asia-Pacific warehouse, we created Figure 2 below. In appendix A3 we added flow descriptions.

Decisions on which flow to allocate to this regional warehouse will become clear when determining the optimal scenario. It could be for example beneficial to still manage flow from Asia-Pacific suppliers to EMEA customers by the central warehouse in Best instead of the new regional warehouse facility.

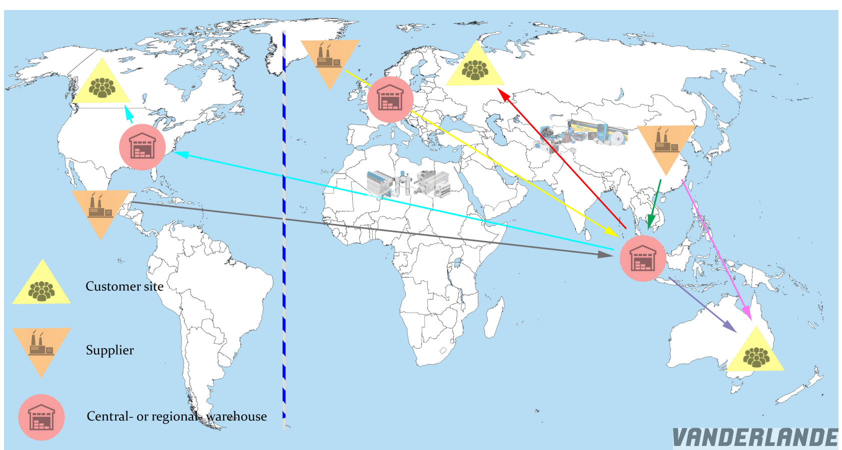

Figure 2: Possible spare parts flow with regional APAC warehouse

FlowNum	Arrow	Color	Decomposed flow	Inbound/Outbound	Direct or via regional warehouse
1	→	Green	APAC supplier to regional warehouse	Inbound	Regional Asia-Pacific warehouse
2	→	Gray	AMER supplier to regional warehouse	Inbound	Regional Asia-Pacific warehouse
3	→	Yellow	EMEA supplier to regional warehouse	Inbound	Regional Asia-Pacific warehouse
4	→	Purple	Regional warehouse to APAC customer	Outbound	Regional Asia-Pacific warehouse
5	→	Blue	Regional warehouse to AMER customer	Outbound	Regional Asia-Pacific warehouse
6	→	Red	Regional warehouse to EMEA customer	Outbound	Regional Asia-Pacific warehouse
7	→	Pink	APAC supplier to RW and RW to APAC customer	Inbound/Outbound	Regional Asia-Pacific warehouse
8			EMEA supplier to RW and RW to APAC customer	Inbound/Outbound	Regional Asia-Pacific warehouse
9			AMER supplier to RW and RW to APAC customer	Inbound/Outbound	Regional Asia-Pacific warehouse

Table 2: Proposed spares flow

This statement refers to our second RQ, namely: *"What partition of the spare parts flows (in and out) are beneficial to manage from the regional Asia-Pacific region warehouse?"*. The answer will depend on where we put the CODP for each specified flow.

The main purpose of the new warehouse facility is to serve *demand from Asia-Pacific customer sites* that is currently fulfilled by the central warehouse. We therefore distinguish this first and most important flow, as spare parts moving towards Asia-Pacific customer sites from the proposed new regional warehouse instead. This refers to flow 1-4 in appendix A3.

Next to Asia-Pacific demand from the central warehouse, there are *direct deliveries* by suppliers throughout whole world (incl. APAC) going towards several Asia-Pacific customer sites. In an ideal situation Vanderlande would put the CODP of current direct spare parts deliveries from suppliers to the proposed new regional warehouse instead. This refers to flow 7-9 in appendix A3.

However there is also a possibility to manage the *flow from Asia-Pacific suppliers to EMEA and AMER customer sites* by the new regional warehouse. This specified flow refers to 1, 5 and 6 in appendix A3.

2.1.3 Order-lines and flow intensities

In order to solve the problem we need information about Order-lines and Flow intensities of flows that may be managed by the Asia-Pacific warehouse (based on previous described CODP decisions).

To determine Order-lines and quantities (pieces sold) of the before mentioned spare parts flows we require two different data sets, namely historical order data and historical purchase data. These datasets contain Flow intensities and order details like for example sales per order, order dates and item descriptions. Because decisions for setting up a warehouse are focused on the future we made the decision to only consider *data from January 2017 until May 2018*, this gives a precise representation about current intensities and revenue.

In addition to these two datasets we enrich data with components from external data resources like for example demand classification, shipping locations of suppliers and customers (from address-book) and corresponding regions, regional industry types or for example Supplier Lead-time. In appendix A6 we motivate why these components are critical for determining the location of a regional warehouse.

To gather the flow data as mentioned above, we need to perform data preperation using Excel pivoting and formulas. We refine data sources so it can be used effectively for solving the location problem in further stage, further description on methods of data preperation is given appendix A6.

In our flow analysis we decompose inbound or outbound flow based on regions. First of all we decompose outbound flow of spare parts that are handled by the central warehouse. This refers to the purple flow (flow number 4) of previous sections. In order to be able to give insight in characteristics of the current spare parts flows moving through the central warehouse, we give a table below of outbound Flow intensities and corresponding sales to the different country regions.

These intensities are the result of fulfilling 1698 Order-lines of Replenishment parts by the central warehouse from APAC demand, 45.646 from EMEA demand and 2.895 Order-lines from AMER demand.

This table is removed for publication.

We conclude that the outbound flow from the central warehouse to the Asia-Pacific region has considerable sales compared to the Flow intensities going to the same region. Moreover, spare parts sales in the AMER region delivered from the central warehouse is much smaller then spare parts sales in the Asia-Pacific region. This is because most AMER sales is registered as direct delivery from suppliers in the used data sets.

This paragraph is removed for publication.

Next to flow handled by the central warehouse we distinguish flow that is shipped directly from the suppliers to customer sites. In the table below we provide Flow intensities of direct deliveries.

This table is removed for publication.

Similar as spare parts flow from the central warehouse to Asia-Pacific, Flow intensities of parts that are delivered direct from suppliers to Asia-Pacific customer sites are quite small compared to the amount of sales represented in the same region. This sentence is removed for publication. In appendix A7 we added the procurement value of direct shipments.

This sentence is removed for publication. While Vanderlande Spare Parts operate a regional warehouse for serving the AMER region, Vanderlande still serves the Asia-Pacific region via central warehouse in Best.

Having discussed all outbound flow we now discuss with inbound flow, flow of spare parts moving from suppliers to the central warehouse. Since inventory levels can change over time and quantities of procurement and sales may vary (e.g. buy package and sell in pieces), inbound Flow intensities does not necessary have to be the same as outbound Flow intensities.

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Flow intensities to Asia-Pacific countries are relatively small compared to cumulative sales of APAC customer sites. This could give an indication that Vanderlande mostly sells capital intensive parts in this region.

2.2 Transportation

In this section we will determine total weight transported to the different regions in the world, we will also formulate a transportation rate distribution for estimating costs in further stage of this study.

2.2.1 Weight and volume transported

Flow intensities do not necessarily reflect shipments, especially since we noticed in previous section that orders shipped to APAC customer sites might contain other type of parts.

Therefore we analysed weight and volume transported to customer sites in different regions. For shipping spare parts around the world, the common denominator is weight. Spare parts usually do not consume a lot of volume [van Venrooij, 2018b].

To illustrate weight and volume transported globally we show a graph in Figure 3, representing distribution of spare parts from the central warehouse to the different country regions.

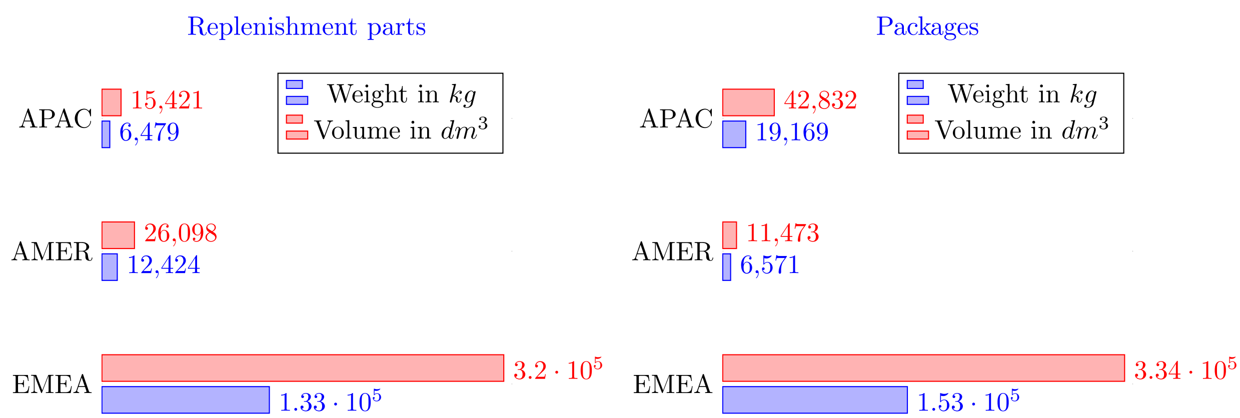

Figure 3: Weight and volume transported to country regions via GDC 01-01-17 31-05-18

In total 13.262 parts with a weight of 6.479kg are shipped to Asia-Pacific customer sites between January 2017 and May 2018, while comparable 101.607 parts with 12.424kg are shipped to AMER in the same time period. From this we can conclude that replenishments parts shipped from the central warehouse to APAC customer sites usually have a more significant weight.

This indicates that we should not only consider number of intensities together with sales, but also details like weight. This is also necessary to determine transportation costs. In appendix A8 we added a graph representing weight and volume transported directly from suppliers to different country regions.

2.2.2 Transportation costs

Similar as in the paper "Applied Materials Uses Operations Research to Design Its Service and Parts Network" of [Sen et al., 2010], we want to determine transportation costs to serve customer sites throughout the world from different possible warehouse locations. The paper of [Sen et al., 2010] gives a relationship between distance, weight and transportation costs invoiced by different carriers.

To illustrate the transportation cost distribution for Vanderlande, we give the graph below with cost per kg within different distance ranges. Next to the cost relationship we present total weight transported in a certain distance range. Because of unavailable data of inbound transport we only consider actual outbound *invoiced transport costs from DHL*. In appendix A9 we provide a table of our cost distribution.

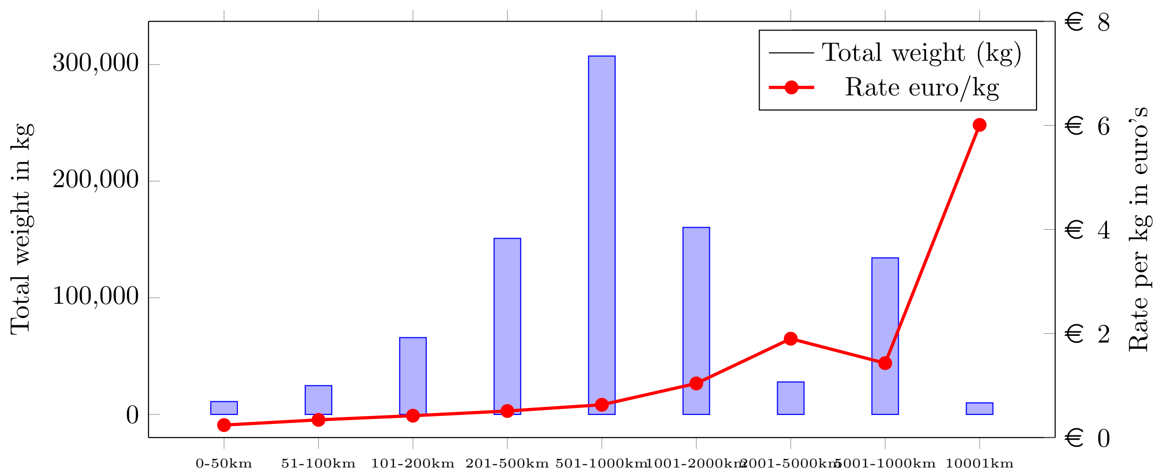

Figure 4: Rate per distance metric 01-03-2017 - 31-07-2018

The transportation rates estimates are based on all different types of services (fast delivery, airline, etcetera).

Higher transportation rates for the distance range of more than 10001 km is presumable because of transshipment of goods between flights. Furthermore we notice lower rates for the distance range of 5001km until 10000km, this is because of shipments by boat transport [van Venrooij, 2018b].

All the above gives answer to the transportation part of our third RQ, namely: *"Which costs are concerned with current way of globally managing spares? (i.e.* ***transportation costs****, warehousing costs, holding cots)"*. First of all we measured weight shipped to customer sites in the different country regions.

Furthermore we determined transport rates for various distance ranges. This will be useful as input for our optimization model in later stage of this study.

2.3 Warehousing costs

To determine warehousing costs for different alternatives in our solution approaches we first analyse warehousing costs components. Furthermore we will do research about storage costs and throughput rates as result from opening public warehouses in several metropolitan cities within the Asia-Pacific region.

Vanderlande Spare Parts operates an outsourced public warehouse at DHL in Best. The public warehouse of DHL in Best invoices warehouse operational costs plus mark-up on monthly bases.

If we multiply the 369.943 units (pieces) kept on stock in the central warehouse with sizes in dm^3 per item, we get to a total size of $807m^3$ of space required for the central warehouse.

Furthermore we can give more characteristics of Global Spare Part's public (central) warehouse. From here we will be able to translate sizes and other requirements for the proposed Asia-Pacific regional warehouse in further stage of this research paper. As follows the characteristics of the central warehouse:

- 3500 pallet locations
- 5500 Shelving location
- 1600 m^2 storage (not dm^3 as mentioned above)
- 5 to 12 FTE personal
- 2,5 FTE Customer service
- Capacity 10.000 PO/outbound lines per month (2017) [van Venrooij, 2018a]

For these kind of warehouse characteristics a warehouse requires separate areas for receiving, shipping goods, storage, order picking, order assembly and offices.

However, for setting up a much smaller warehouse there is no need for operating all these separate area's. In a outsourced public warehouses there are possibilities for getting charged per throughput and using shared area's for receiving, shipping goods, order picking, order assembly and offices. Therefore we will determine required throughput rates and storage costs that will be used input parameters for our model.

In special occasions Vanderlande already delivers spare parts to Asia-Pacific customer sites via a public warehouse in Australia. From the tarrifs hold by Visa Global Logistics it is possible to estimate throughput rates for Order-lines in the proposed regional warehouse. We added these tariffs in appendix A11.

When estimating costs for fulfilling Order-lines using tariffs of Visa Global Logistics, we come to a throughput rate of €8.72 per order-line. This is based on sending approximately 40 Order-lines per week (1400 per year) towards Asia-Pacific customer sites. This throughput rate estimation only applies in case of using public warehouses in Australia.

In order to get an Order-lines throughput rate estimate for alternative countries we multiply the throughput rate by a weighted factor on gross domestic product (GDP) per capita. To give a numerical example, GDP per capita in Japan is €38.428 and in Australia €53.799. From here we assume that the throughput rate per Order-lines in Japan is 38/54 times lower then the estimated €8.72 using tariffs from Visa Global Logistics.

For the Netherlands we apply a throughput rate of €3.11 per Order-lines given in the calculation of ordering cost in the analysis of current inventory modelling in Section 2.5.4.

The graph below illustrates how the throughput rate (in red) is strongly dependent on the location of the public warehouse. This is because we use weighted factors on GDP per capita.

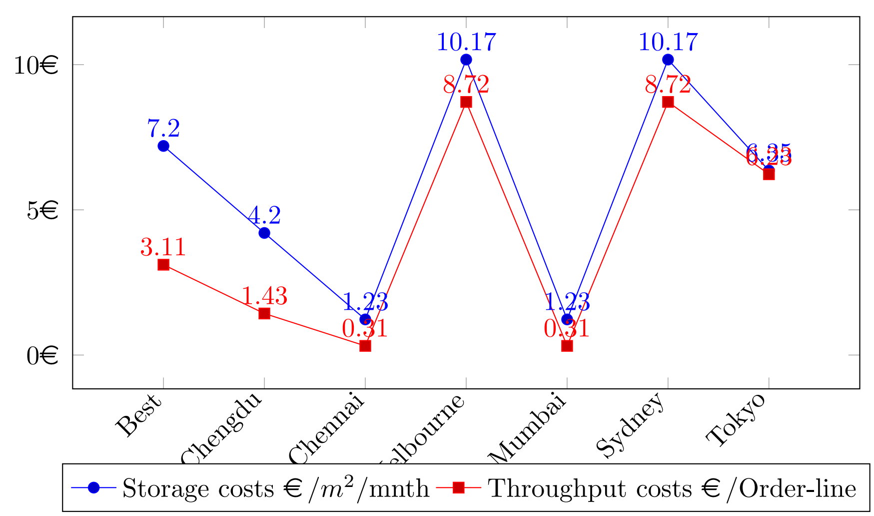

Figure 5: Warehousing storage and throughput costs by alternative RW location

Throughput rates and storage costs are dependently on location of the new regional warehouse. For the estimation of the storage costs per country we use the additional (expensive) space rate of €7.2/m^2/month paid by Vanderlande Spare Parts to their outsourced central warehouse at DHL as base-rate.

In order to get an estimate for storage space rate per country we multiplied the storage costs of DHL by a weighted factor based on worldwide property index used from a publication of [NationMaster, 2018]. The warehouse storage rates (€/m^2/mnth) are given in Figure 5 (blue line).

In resolution with the warehousing costs part of our fourth RQ *"Which costs are concerned with current way of globally managing spares? (i.e. transportation costs,* ***warehousing costs****, holding costs etcetera)"*, warehousing costs are built up on components like space, handling activities and documentation. For setting up a small regional warehouse, like the new Asia-Pacific warehouse facility, we require throughput rates and storage space rates per country.

2.4 Import duties

Duties for importing spare parts to the Asia-Pacific region can differ significant from country to country, obviously this should affect decisions on warehouse locations. In this section we will determine which import tariffs will have to be paid when Vanderlande locates a warehouse facility at one of the different possible warehouse locations

Import duties depend on what type of goods are to be imported, as given in the graph below most items are from chapter 84 and 85. These chapters belong import duties for machinery and mechanical appliances or electrical equipment [Taxation and Union, 2018].

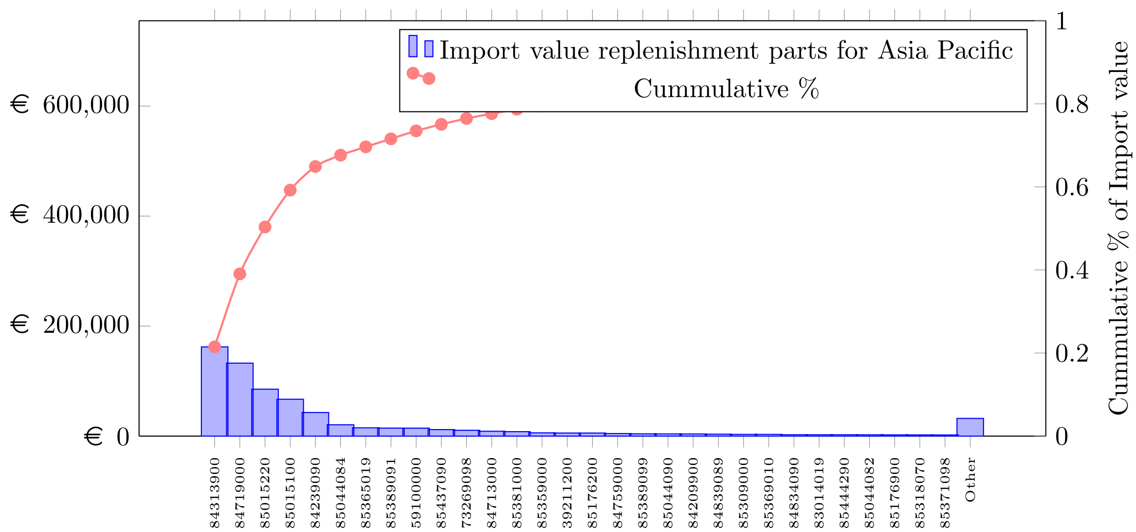

Figure 6: Import values Asia-Pacific demand per product chapter 01-01-17 until 31-05-18

What we conclude is that the vast majority of spare parts meant for Asia-Pacific customer sites will follow chapter 84 and 85 import tariffs.

When comparing import tariffs of products from this chapter, we get various percentages for importing spare parts from Europe to alternative counties in the Asia-Pacific region. The vast majority of spare parts suppliers are located in Europe, therefore we assume all import tariffs will apply by importing parts from Europe to eventually alternative countries of possible warehouse locations in the Asia-Pacific region.

	AU	BN	CN	HK	ID	IN	KH	MM	PH	SG	TH	TM	TW	VN
Percentage of purchasing value	2%	0%	4%	0%	7.5%	5%	0%	5%	1%	0%	3%	2%	5%	0%

Table 3: Import tariffs per country Asia-Pacific region

We can calculate import costs by multiplying the import value of specified flows by import tarrifs used as standard at the country of the specific warehouse location. Next to import costs for the moving goods through the regional warehouse, Vanderlande has to pay duties for importing goods to countries of final delivery at customer sites. In other words, when Vanderlande will set up the proposed new regional warehouse in Australia and most customer sites are in Australia, Vanderlande has to pay import duties only once.

In almost all countries there are possibilities of operating a bonded warehouse, in this case Vanderlande does not have to import goods to the country of warehouse facility. However, maintaining bonded warehouses are expensive and complicated. From this view it will not be beneficial to use this kind of alternatives [van Venrooij, 2018b].

2.5 Inventory

In order to give answer to our third RQ's and eventually determine solution approaches with relevant literature, we have to gain knowledge about current used inventory systems.

Vanderlande Spare Parts replenishes their inventory based on order-level and purchase advise from the Slimstock inventory software (Slim4). Vanderlande uses the following steps to manage inventory:
1. Demand classification
2. Demand forecasting models and parameters
3. Inventory policies and parameters
4. Implementation of inventory policies.

We will analyse each of the above mentioned steps for determining currently used inventory policies.

2.5.1 Current demand classification

By using demand classification, Vanderlande Spare Parts makes decisions on quantities of items to keep on stock at a central- or regional warehouse.

Of course, now the question raises what and what not to keep on stock. Vanderlande Spare Parts regularly keeps Replenishment parts on stock. Only with exception, Vanderlande Spare Parts orders a specific part with long Supplier Lead-time to support a project in relation to project-planning reasons.

Furthermore, decisions on what item to keep on stock are defined by logistical parameters [van Venrooij, 2016]:
1. A replenishment part should be replenished last 24 months, with 4 months of customer-orders.
2. A replenishment part should be replenished last 12 months, with 2 months of customer-orders.

From these above mentioned decision criteria we know which parts are candidate to keep on stock.

All parts that we could keep on stock are on itself again dividable in different demand classifications.
- Normal demand: Frequent demand occurrences.
- Lumpy demand: infrequent demand highly variable size.
- Irregular demand: infrequent demand occurrences.
- Slow moving demand: low average demand per period (infrequent demand and/or low demand size).
- Other: all demand zero, new, user controlled, obsolete, promotion article or obsolete promotion.

These classifications are based on mean demand interval (high is non-intermittent and low demand inteval is intermittent), mean demand size (low size is slow) and the coefficient of variation of demand sizes (high is lumpy and low demand size is clumped) [Boylan et al., 2008].

In extension of the demand classification we analysed which amount of items in the central warehouse are currently hold by the different classifications, this is provided in appendix A12. From all Stocked items provided by use of the logistical parameters above, most items are considered as slow moving demand.

Demand classification of items will differ when specific parts are managed from a regional warehouse in the Asia-Pacific region, this because worldwide demand gives a different demand representation than demand from only the Asia-Pacific region itself. By using relevant literature in next chapter, we will be able to determine demand classification for inventory at the new Asia-Pacific warehouse facility.

2.5.2 Current forecast

Within current forecast, the vast majority of items are calculated by Slim4 based on *only demand class and life cycle*. Selling spare parts is not depending on external factors like seasonality, therefore it will not be necessary to use complicated forecasting techniques in further stage of this study.

We can simply use the same demand patterns as the previous time period, taking into account a certain growth for a specific year.

2.5.3 Inventory policies

Logistical Support orders the above forecasted parts periodically at the start of a new day if the inventory level falls below a specified reorder point. In other words, Logistical Support uses an periodic review inventory policy. All replenishment actions of the used Slim4 software within Vanderlande Spare Parts are based on periodic review inventory policies.

Within replenishing from the Slim4 software, variable or fixed lot sizes can sometimes differ. This because some spare parts are for example expected to be ordered in large quantities. Within different policies used, Logistical Support usually only periodically replenishes orders when the inventory position (IP) falls below a specified re-order point s.

In answers our fourth RQ: *"In which way is the global spare parts department currently modelling inventory?"*, the above mentioned methods of inventory management correspondents with inventory policies from the periodic review family.

2.5.4 Inventory costs

Total relevant yearly inventory costs is usually determined by order sizes, demand rates, ordering costs and carrying charges. To get an image of how Vanderlande calculates relevant inventory costs we gathered information about ordering costs and carrying costs.

It is difficult to determine the required ordering costs A, and carrying costs r for this formula. Based on calculations of input parameter by [van Oers, 2018], senior spare parts coordinator at Vanderlande Spare Parts, we are able to determine order-sizes and reorder-points in further stage of this research. The derivation of ordering costs A and carrying costs r are provided in appendix A13.

Besides Vanderlande Spare Parts maintains a 95% Cycle service level (Probability $P1$ of no stockout per replenishment cycle) for Fast movers and a 85% Cycle service level for Slow movers.

These input parameters are required for determining total relevant yearly costs of holding inventory in an Asia-Pacific warehouse, discussed in later stage of this study.

If we come back to our 4th RQ: *"Which costs are concerned with current way of globally managing spares? (i.e. transportation costs, warehousing costs, inventory costs and import costs)"*, the result of these service-levels together inventory systems used at Vanderlande, give the situation that currently €4.4 million (2017) worth of parts are kept on stock at the central warehouse warehouse in Best.

2.6 Benefits

We will analyse (dis)benefits by determining factors like supply chain strategy, political risk and for example Customer order Lead-time, that should affect decisions on opening an Asia-Pacific warehouse facility.

2.6.1 Vanderlande's strategy

As stated in the introduction, the mission of Vanderlande acknowledges that Vanderlande "improves the competitiveness of customers through value-added logistic process automation" [Vanderlande, 2016].

Vanderlande realizes this mission by executing their strategy named How to win. Setting up a regional warehouse in the Asia-Pacific region effects factors within this underlying strategy. Below we list which factors could be affected with a service network redesign. Besides we give possible reasons why this could be affected. This has to be proven by effects of practice given by literature in next phase of this research.

• Market, customers and competition: a new regional warehouse could increase the ability to increase marketshare and competition in Asia-Pacific region because Vanderlande Spare Parts might access new regional customers who are currently buying spare parts from a competitor.

• Flexible processes: a new regional warehouse might increase flexibility because Vanderlande Spare Parts will be able to also sent goods through an Asia-Pacific warehouse next to the current central warehouse in Best and regional North, Central and South America warehouse located in Acworth.

• Products and solutions: a new regional warehouse could increase their ability to deliver more variants of products and solutions to Asia-Pacific customer sites, for example selling certain services contracts will become feasible in this market. Currently Vanderlande is not always able to deliver spare parts within desired time periods.

2.6.2 Lead-times

In the illustration below we give Customer order Lead-time as result of the current order fulfilment process.

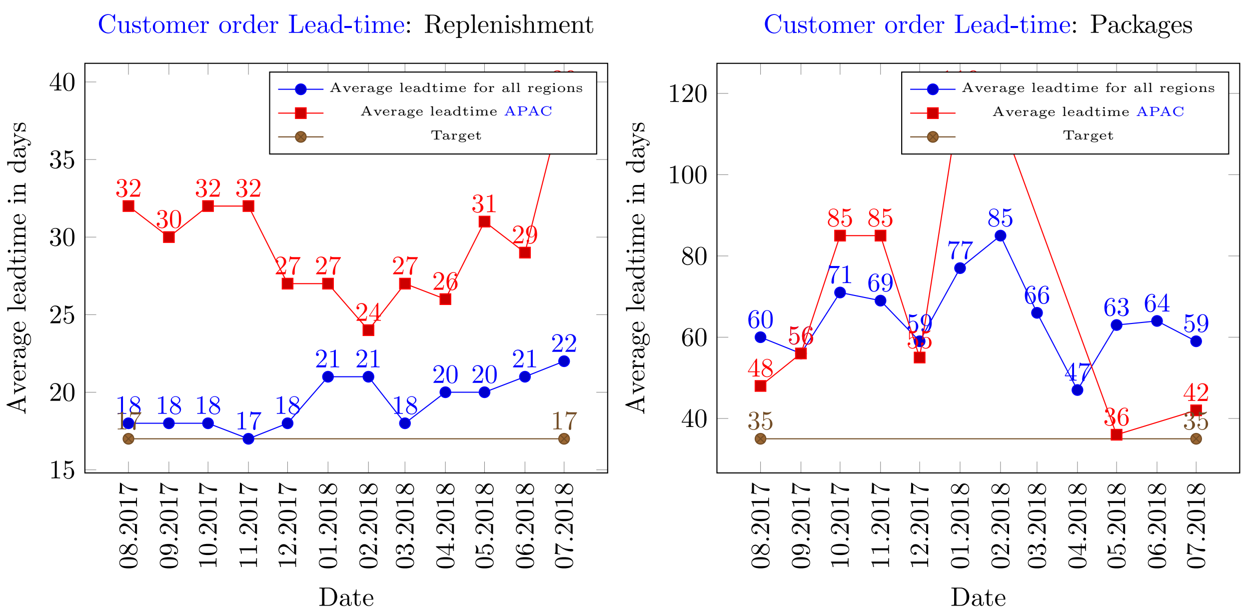

Figure 7: Average Lead-times Replenishment parts and Packages in APAC region

It is clear that Lead-times are longer for customer sites in Asia-Pacific, we count approximately 10 days on average. In order to determine how much advantage Vanderlande can obtain from setting up a regional warehouse we are interested in the causes of these long Lead-times. This is important for determining how Vanderlande will be able to deliver a higher service to Asia-Pacific customers with this new warehouse.

First of all we have to count extra Customer order Lead-time for travel time, furthermore clearing goods in Asia-Pacific takes around 3 days on average. The approximately last 4 days of longer lead-times are caused because Logistical Support usually waits until a significant shipment can be sent to a specific country.

2.6.3 Exchange rate stability

Exchange rate stability is one of the factors that should influence decisions on where to locate the regional Asia-Pacific warehouse. From a paper named the "Trilemma Indexes" of [Aizenman et al., 2018] we found an exchange rate stability index. However we think that using effective exchange rate indices of the [BIS-Bank, 2017] will provide better results. In the table below we provide the exchange rate stability per country.

Country	**NL**	**HK**	**SG**	**JP**	**AU**	**TH**	**CN**	**IN**	**PH**	**ID**
Standard deviation exchange rate indices	4.25	8.76	8.96	9.35	10.19	11.74	14.38	19.66	26.02	111.64
Exchange Ranking	1	2	3	4	5	6	7	8	9	10

Table 4: Exchange range stability index per country Asia-Pacific region

2.6.4 Global political risk index

In the table below we give a ranking of Asia-Pacific countries by most recent (2018) Global Political Risk Index (GPRI). The GPRI is the overall measure of political risk for a given country [NBER, 2018].

Country	**HK**	**SG**	**TW**	**AU**	**JP**	**NL**	**TH**	**IN**	**CN**	**ID**	**PH**	**VN**	**KH**	**BN**	**MM**
Global political risk index number	92	91	89	85	85	84	76	70	69	69	68	68	67	64	63
Ranking	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Table 5: Global Political Risk Index per country Asia-Pacific region

2.6.5 Dangerous goods

Some spare parts are considered as Dangerous goods, carriers of Vanderlande do not accept these type of goods for its air transportation. Examples of Dangerous goods are: batteries, oil hydraulics, sprays and other chemicals. A significant amount of order's consist of Dangerous goods. Because of only being able to use certain transport carriers, this can delay delivery time for finalizing complete orders.

In Figure 8 below we illustrate Flow intensities and sales amounts of Dangerous goods per region.

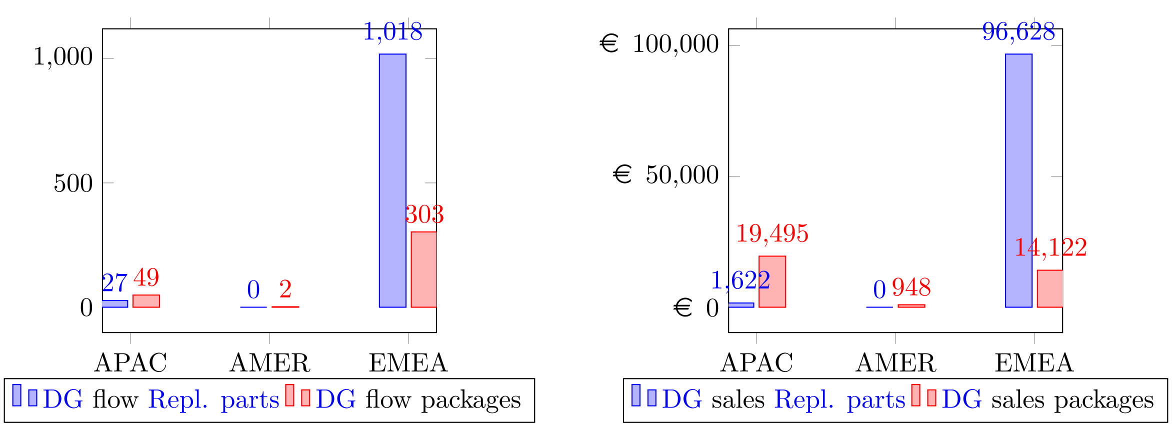

Figure 8: Flow intensities and sales packages dangerous goods via GDC 01-01-17 - 31-05-18

As can be noticed, a significant amount of orders consisting Dangerous goods are represented by Packages demand. The complete order of the Packages only fulfilled once the Dangerous goods within the Packages are also delivered to the customer site. Because these goods are sent by for example shipping transportation, this causes extremely long Lead-times for fulfilling these orders.

To give a more clear insight, in total Vanderlande delivered 122 Packages towards Asia-Pacific customer sites from which 5 Packages consisted these dangerous parts (49 parts). This represents approximately 4% of Packages orders from Asia-Pacific demand.

2.6.6 Criticality

Criticality expresses the importance of a part in case of system failure, this is important for the customer's systems uptime. We define the following classifications of *an WP&P sorting installations* spare parts:

- High, the failure has to be corrected and the spares should be supplied immediately, because these parts cause high losses due to non-availability of equipment.
- Medium, the failure can be tolerated with temporary arrangements for a short period of time, during which the spare can be supplied.
- Low, the failure is not critical and causes only minor disruptions [van den Bosch, 2017].

From the total of 1.016 replenishment *WP&P Order-lines* sent between 1 January 2017 and 31 May 2018 from the central warehouse towards Asia-Pacific customer sites, *439 orderlines can be considered as parts with high Criticality*, 173 with medium Criticality and 2 with low Criticality.

However this *only gives an indication about the Criticality of WP&P spare parts* since for Airports we do not have information available about Criticality.

When referring back to our 5th RQ: *"What are other (beneficial) factors of Vanderlande that should be considered when setting up a new regional Asia-Pacific warehouse?"*, we could expect shorter Lead-times of orders and ability to deliver for example criticality parts timely to customer sites. Disadvantages for setting up a regional warehouse at a specific location might be political risk or exchange rate stability.

2.7 Potential Asia-Pacific

A growth path can be determined by analysing growth in installed base and historical spare parts sales.

In opposite of determining Flow intensities, we used the financial accounting data from the spare parts department to determine historical yearly replenishment sales. This data is different from analysis of Flow intensities because Vanderlande's accounting standards use different activity's than historical order data. Therefore in some cases Packages sales is considered as replenishment sales.

On average there is growth in Asia-Pacific replenishment sales the last 3 years, only last year (2017) there is a stagnant sign of replenishment sales within this region. This sentence is removed for publication. Relative growth is strongest in the Europe, Middle-East and Africa region. In appendix A14 we provide historical replenishment sales growth per country and per customer within the Asia-Pacific region. Most replenishment sales is represented by Australian WP&P customer sites.

If we come back to our 6th RQ *"How could we interpret potential of future Asia-Pacific spare parts sales?"*, Vanderlande Spare Parts their statement that "Vanderlande is currently facing a strong growth, amongst others in the Asia-Pacific region" is not entirely correctly since relative growth in EMEA is stronger. But we notice growth in this region, this is still beneficial for opening a warehouse in Asia-Pacific region.

Next to growth path, Vanderlande Spare Parts indicated that in initial project phase relatively more parts are sourced in Asia-Pacific than in after-sales phase, from this we conclude that there might be more potential for the regional warehouse if we would source from surrounding countries of Asia-Pacific customer sites.

2.8 Conclusions

This paragraph is removed for publication.

By using the relationships between distance, weight and transportation costs we will be able to determine *transportation costs* for alternative warehouse decisions in later stage of this study.

Import duties depend on what type of goods are to be imported. Most items delivered to Asia-Pacific customer sites are from chapter 84 and 85. We will have to consider paying import costs for moving goods through the regional warehouse and besides for final delivery to customer sites.

Vanderlande Spare Parts makes decisions on what items to keep on stock. If a certain part is replenished 4 times last 24 months and minimal 2 replenishments within the last 12 months, then this part should be kept on stock. All items on stock are on itself again dividable in different demand classifications.

Within *current forecast* of the Vanderlande Spare Parts the vast majority of items is calculated based on only demand class and life cycle, therefore we will not have to consider complicated forecasting techniques.

Vanderlande Spare Parts maintains a 95% Cycle service level for Fast movers and 85% for Slow movers. Using the same serivce-levels, input parameters like ordering and carrying costs together with inventory models out of literature we will be able to determine the *required inventory for the Asia-Pacific warehouse.*

Next to costs perspective we consider *benefits* from setting up a regional warehouse, that may even be far more important.

3 Literature review

This chapter contains the literature review, relevant literature will give the direction to our solution approaches. In answer of our 7th RQ: *"What solution approaches will solve our research problem?"*, decisions on where (and if) to set up a warehouse in this regions are based on the interaction between transportation costs, warehousing costs, import costs, inventory management and (measurable) benefits. There is several literature available for solving this type of multi criteria MCDA problems. This counts the same for determining an optimum inventory allocation for the different alternatives.

In resolve to our MCDA problem *we only need to consider discrete modelling* withing applying solution approaches to find the new regional Asia-Pacific warehouse location, because:

- We will only use a select set of locations because of connection requirements to distributor's.

Using analysis of factors that could be affected by opening a regional warehouse, together with possible effects from relevant literature, we will be able to provide benefits and risks for opening the new facility.

3.1 Transportation distances

In the solution approaches we will apply certain distances measures for estimating transportation costs by using our transportation costs distribution. A costs distribution that is on itself again, also built by using identical distance measures. Using longitudes and latitudes we will be able determine distances between suppliers, alternative warehouse locations and customer sites.

Euclidian distance applies for some network location problems as well as some instances involving conveyors and *air travel*. Some electrical wiring problems and pipeline design problems are also examples of Euclidean distance problems [Francis and White, 1974]. The function of Euclidean distance is:

$$f(x, y) = \sum_{i=1}^{m}[(x - a_i)^2 + (y - b_i)^2)]^{0.5} \tag{1}$$

where,
$P_i = (a_i, b_i)$ are the coordinates of the locations of customer sites i
$X = (x, y)$ is the coordinates of the location of new warehousing facility

The book "Geographic Information Systems and Science" of [Longley et al., 2001] give the following formula for calculating the euclidean distance or "Great Circle" between two points with latitude δ_i and longitude φ_i [Tarboton, 2017]. It is wise to be careful when using a GIS to analyse data in latitude and longitude rather then projected coordinates, because serious distortions of distances may result [Longley et al., 2001].

$$d(\delta_1, \varphi_1, \delta_2, \varphi_2) = r \sin \delta_1 \sin \delta_2 + \cos \delta_1 \cos \delta_2 \cos(\varphi_1 - \varphi_2) \tag{2}$$

where, r_e *= earth radius (in km, 6367)*
δ_i = latitude
φ_i = longitude

Since most freight is shipped to customer sites by air travel, we can apply euclidian distance for most instances. However, Vanderlande might also ship goods to certain customer sites by road travel from the proposed new warehouse location. This requires different distances measures.

In nearly all locations within the *United States*, the straight-line distance is an adequate proxy for travel distance, after applying a ratio of travel distance to straight-line distance of about 1.4 [Boscoe et al., 2011]. Similar research is unavailable for Asia-Pacific countries like China or Australia, from common sense we conclude it would be at minimum the same ratio as given in the paper of [Boscoe et al., 2011].

We have to ask ourselves whether we should apply ratios in our solution approaches for determining transportation costs. If impacts on costs are relatively low it will give unnecessary complexity.

3.2 Inventory allocation

Literature from common used demand classification and inventory policies will give direction to inventory modelling for the regional warehouse facility in our solution approaches.

3.2.1 Demand classification

Different demand classifications require different inventory models. Using information out of the lectures of the course "Advanced inventory management" given by [van der Heijden, 2017], we are able to determine each demand classifications using the following parameters:

- p = average number of periods between demand events (≤ 1.18).
- cv^2 = squared coefficient of variation of the demand size [van der Heijden, 2017].
- ds = Average demand sizes at demand events (≤ 2).

In Chapter 2, Section 2.5.1., we provided all different possible demand classifications.

3.2.2 Inventory policy's

It can be demonstrated that under general condition, the system that minimizes the total of review, replenishment and carrying costs will be a policy member of the periodic review family. However, since the computational effort to obtain the best values for control parameters are more intense than for continuous review policies we will focus on policy members of the continuous review family [Silver et al., 2016].

From the continuous review family, the (s,S) system can be shown to have the total costs of replenishment, carrying inventory, and shortage that are not larger than those of the best (s,Q) system. However, the computational effort to find the best (s, S) pair is substantially greater. Thus, the (s,Q) may be the better choice [Silver et al., 2016].

In our study we are not seeking for an inventory policy to minimize costs, but we want to gather an estimate for managing inventory from the Asia-Pacific facility. Therefore we rather choose a policy that gives roomy estimates than a policy that minimizes costs. From this view, the (s,Q) policy will be the right choice.

We distinguish the decision rules of fast normally distributed items and slow Poisson distributed items by nature of determining the required reorder points s and fixed order sizes Q.

There is a wide choice of criteria for establishing safety stocks (SSs). The choice of a criterion is a strategic decision [Silver et al., 2016]. Based on both customer service perspective and beside being able to use most simple-minded approaches, establishing the right SSs can by done using the following common measures:

- Specified Probability ($P1$) of No Stockout per Replenishment Cycle: Cycle service level .
- Specified Fraction ($P2$) of Demand to Be Satisfied from Inventory: Fill rate [Silver et al., 2016].

Executives often want to control the percentage of total volume ordered that is available to satisfy customer demand known as Fill rate, not the percentage of cycles without a stockout. Fill rate often is a better measure of inventory performance, as cycle service level merely indicates the frequency of stockouts.

When supply and demand are stable, Fill rate tends to be higher than Cycle service level. Conversely, with demand and lead time variability, Fill rate will be lower than Cycle service level, and volume of stockouts will be high. Demand variability is the dominant influence on safety stock requirements [King, 2011].

Managing Fast-moving inventory

In fixed order-quantity continuous review (s,Q) system we reorder if the current inventory position (IP) will fall below the reorder point s.

Throughout this whole study we define expected demand during Supplier Lead-time (L) as x_L and the standard deviation as σ_L. We can calculate x_L simply by multiplying x_{day}*(L), and, σ_L can be calculate by multiplying the daily σ by $\sqrt{L}$.

We can derive k for the safety stocks from the Fill rate ($P2$) by solving k from $G(k)$ (normal loss function) for each item using the following equation out the book "Inventory Management in Production and Supply Chains" from Silver Pyke and Thomas (5):

$$G(k) = \frac{Q(1-P2)}{\sigma_L} \tag{3}$$

Furthermore, in a (s,Q) policy, we determine reorder point s by:

$$s = x_L + \text{k} * \sigma_L \text{ (SS)} \tag{4}$$

Next to reorder point s we need order sizes Q for the decisions rules of the required (s,Q) inventory policy. Using the specified ordering and carrying costs from previous chapter in 2.5.4 and the standard EOQ formulas we will be able to determine the fixed lot-sizes.

• Total cost per year:

$$TRC(Q+SS) = \frac{A*D}{Q} + v*r*SS + \frac{v*r*Q}{2} \tag{5}$$

• On hand stock:

$$E[OH] = \frac{Q}{2} + k*\sigma_L \tag{6}$$

Where D = Demand/year, v = value/piece, r = holding cost rate and A = ordering costs

Managing Slow-moving inventory
For determining a reorder point s and order size Q for slow-moving poisson demand, the book "Inventory Control" from Sven Axsäter suggest to use an (s-1,s) inventory model. Or: one-for-one replenishments. Similar as in the book of Axsäter, we will use the following notation for this (s-1,s) inventory model:

- Demand Poisson(D) where D = Demand per year
- (s-1,s), inventory model, or: one-for-one replenishments
- T = mean repair shop throughput time (yr)
- s = stock level: total amount in repair and distribution
- $P2$ = fill rate, fraction of demand satisfied without delay [Axsäter, 2015]
- DT = Demand during Supplier Lead-time

$$P2 = \sum_{n=0}^{s-1} \frac{(DT)^n * e^{DT}}{n!} \tag{7}$$

In answer of the second part of our eight RQ *"And when locating this Asia-Pacific warehouse, which models can be used for determining an optimal stock allocation?"*, we follow the normal (s,Q) inventory policy for Fast movers and the (s-1,s) inventory poisson inventory model for Slow movers.

3.3 Benefits from literature

Partially we could determine (dis)benefits from setting up this new warehouse facility by exploring a qualitative literature study. With this study, we may conclude that certain events occur as consequence for setting up this regional warehouse facility.

3.3.1 Supply chain strategy

The design of a distribution network will affect the supply chain for several years. Distribution network decisions must support the strategic objectives of the company in order to ensure the highest possible supply chain profitability [Chopra and Meindl, 2013]. All network design decisions affect each other and must also be reconsidered as a firm grows or as the market conditions change [Colliander and Tjellander, 2013].

The added complexity of increased product profilation, globalisation and consolidation among retailers and manufacturers has put pressure on warehouses to be both responsive and cost effective [Maltz and Dehoratius, 2005]. A company's competitive strategy has large impact on the design decisions within the supply chain network. At the extremes, a focus on cost efficiency would probably seek the lowest cost location whereas a focus responsiveness would lead to location of facilities closer to the markets independent on cost [Chopra and Meindl, 2013].

While cost reductions are, of course, very desirable, they are not an end in themselves. The main rationale for orchestrating a local alliance is to increase competitive advantage. As one executive put it, "For us, the reason for this venture is market impact. Cost reduction is important but secondary" [Bowersox, 1989].

To create a successful firm a company's supply chain strategy and competitive strategy must be aligned in a so called strategic fit. If there is a mismatch between supply chain design and customer needs restructuring of the supply chain must be implemented or alternatively changes to the competitive strategy must be made [Chopra and Meindl, 2013].

From literature it is known that opening warehouses give strategic benefits. Usually product, promotion, and price are the traditional competitive ingredients, while time and place competencies take a back seat.

Superiority over the competition means placing a premium on being easy to do business with. Strategic vision, however, calls for more than readiness to serve the customer; it calls for a willingness to offer extra, value-adding services. The objective, of course, is to become a preferred supplier of key customers. Companies committed to strategic use of logistics usually outperform the competition in speed and consistency of order cycle [Bowersox, 1989].

Order Lead-time can be a significant differentiator between competitors. The quality of products is such that competitive advantage is gained through fast, timely and accurate delivery. The most effective warehouses are those that have reduced Lead-times whilst maintaining quality at a reduced cost [Richards, 2011].

[M., 1996] discusses strategic fit in similar terms and states that not only is it fundamental for the competitive advantage but also for sustaining said advantage as it is significantly harder for competitors to match an integration of functions and activities rather than to imitate a sole function in the supply chain. [Mintzberg et al., 2009] explain that it is with systems of production a company competes in the marketplace and not with its products. In order to achieve sustainable advantage [M., 1996] states that positioning the company is not enough since it is closely connected to trade-offs [Colliander and Tjellander, 2013].

Managing trade-offs within the warehousing decisions is fundamental to the role in supply chain management, we usually design the trade-off between customer service levels, low costs and low inventory [Richards, 2011]. Trade-offs are important for competition and as well essential for the supply chain strategy [Colliander and Tjellander, 2013].

Vanderlande Spare Parts does not own an explicit formulated competitive strategy. From the here we conclude that *before making network distribution decisions for the Asia-Pacific region, Vanderlande Spare Parts should design trade-offs for eventually setting strategic supply chain objectives.*

Highlighted by work of [Baker, 2008], [Gallman and V.Belverde, 2011] and Napolitano [1997], there are several well known trade-offs between the desired levels of service and cost in supply chain management.

Because of the unavailability of similar trade-offs within the department, we are not able to conclude whether Vanderlande Spare Parts will carry out its strategy with opening a regional warehouse to serve Asia-Pacific customers.

However, the mission of Vanderlande is to improve the competitiveness of its customers through value-added logistic process automation. By controlling the supply of spare parts in Asia-Pacific region via the new regional warehouse facility, Vanderlande will reduce Lead-times of parts to customer sites.

Customer order Lead-time of spare parts is a critical factor for the customers system uptime. Increasing customer's system uptime can be generally recognized as improving competitiveness of Vanderlande's customer sites. From this perspective, we may conclude that Vanderlande will execute the overall mission statement with setting up an Asia-Pacific warehouse facility.

3.3.2 Exchange rates

Fluctuations in exchange rates are common and have a significant impact on the profits of any supply chain serving global markets [Chopra and Meindl, 2013].

It is important that companies keep ahead and understand the impact of currency fluctuations. One of the main problems for exporters is when buying in a currency with a high valuation and then selling in a weaker currency. Any strong changes affecting currency will impact profit margins [Trudgian, 2016].

However in case of selling spare parts at Vanderlande, exchange rate risks are usually charged to customers. Besides Vanderlande Spare Parts maintains Euro valuta among different warehouses [Kriz, 2018].

3.3.3 Political factors

The political stability of the country under consideration plays a significant role in location choice. Companies prefer to locate facilities in political stable countries where the rules of commerce and ownership are well defined [Chopra and Meindl, 2013].

Political instability and trade restrictions through tariff and duty imposition are two of the main factors that impact the distribution network decisions. Terrorism and corruption are other areas that may trigger operational risk to the supply chains. Fraude and illicit trade also are the political factors that should be considered [Lecturer, 2017] for network decisions.

Since Vanderlande sells commonly products with a high degree of intellectual property, we should take this into account in our location decisions.

When we refer back to our ninth RQ *"What qualitative (dis)benefits can we demonstrate from literature for setting up this regional warehouse?"*, we can support from literature that Vanderlande will carry out their mission statement by controlling the supply of spare parts from an Asia-Pacific warehouse facility.

However, within the global spare parts department there is no main competitive strategy available. From here we are not able to translate this in requirements of the design of a distribution network within Vanderlande Spare Parts.

Furthermore, from literature it is given that it is important to consider political and exchange rate stability in decisions in alternative warehouse locations.

3.4 Multiple-criteria decision analysis

Multiple-criteria decision analysis is a sub-discipline of operations research that explicitly evaluates multiple conflicting criteria in decision making (both in daily life and in settings such as business, government and medicine). Conflicting criteria are typical in evaluating options: cost or price is usually one of the main criteria, and some measure of quality is typically another criterion, easily in conflict with the cost [Madurika and Hemakumara, 2015].

MCDA problems can be divided into two major classes with respect to the way the weights of the alternatives are determined: Compensatory and Outranking Decision Making. The example of the former is Analytical Hierarchy Process (AHP) and the latter is Elimination and Choice Expressing Reality. The basic working principle of any MCDA method is same: Selection of Criteria, Selection of Alternatives, Selection of Aggregation Methods and ultimately Selection of Alternatives based on outranking [Majumber, 2015].

In our study we focus on Thomas Saaty's compensatory Analytical hierarchy process MCDA method. Since AHP has an simplified structure of a decision process, allows both quantitative and qualitative criteria, allows to determine the trade-offs among criteria and imitates the way human think about the decision making [Moghadam et al., 2009]. Because of these aspects, we think it fits best with solving our problem.

3.4.1 Analytical hierarchy Process

To explain this method we will use a simple example [Pereyra-Rojas and Mu, 2017], let's suppose that Jane has three job offers and must determine which offer to accept. For the ith objective (in this example, i=1,2,3,4) the AHP generates a weight w_i for the ith objective. For convenience, the chosen weights always sum to 1. Suppose that for this example, we have found Jane's weight to be: w_1=0.5115, w_2=0.0986, w_3=0.2433 and w_4=0.1467.

The weights indicate that a high starting salary is the most important objective, followed by interest of work, nearness to family, and quality of life in the city where the job is located.

Next suppose that Jane can determine how well each job "scores" on each objective. For example, job 1 best meets best objective of a high starting salary but "scores" worst on all other objectives.

Given Jane's weights and the score of each job on each objective, how can Jane determine which job offer to accept? For the ith job offer (i=1,2,3), compute job offer i's overall score as follows:

$$\sum_{i=1}^{i=4} w_i(\text{job offer i's score on objective i}) \quad (8)$$

Objective (i)	Job 1	Job 2	Job 3
Salary	0.571	0.286	0.143
Quality of life	0.159	0.252	0.589
Interest in work	0.088	0.669	0.243
Proximity to family	0.069	0.426	0.506

Table 6: Jane's score for each job and objective

Computing each job's overall score, we obtain for job 1 = .5115(.571) + .0986(.159) + .2433(.088) + .1467(.069) = 0.339, similar for job 2 0.396 and for job 3 0.265. Thus, the AHP would indicate that Jane should accept job 2 [Winston, 1994].

Obtaining weights for each objective
Suppose there are n objectives. We begin by writing down an n x n matrix (known as the pairwise comparison matrix) A. The entry in row i and column j of A (a_{ij}) indicates how much more important objective i is then objective j. "Importance" is to be measured on an integer-valued 1-9 scale. For all i, it is necessary that $a_{ii} = 1$. If, for example, $a_{13} = 3$, objective 1 is weakly more important than objective 3. If a_{ij} = k, then for consistency, it is necessary that $a_{jk} = \frac{1}{k}$. Thus, if $a_{13} = 3$, then $a_{31} = \frac{1}{3}$ must hold.

Suppose there are n objectives. Let w_i = the weight given to objective i. To describe how the AHP determines the w_i's, let's suppose that decision maker is perfectly consistent. Then her pairwise comparison matrix should be of the following form:

$$\begin{bmatrix} \frac{w1}{w1} & \frac{w1}{w2} & \cdots & \frac{w1}{wn} \\ \frac{w2}{w1} & \frac{w2}{w2} & \cdots & \frac{w2}{wn} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{wn}{w1} & \frac{wn}{w2} & \cdots & \frac{wn}{wn} \end{bmatrix} \tag{9}$$

For example, suppose that $w_i = \frac{1}{2}$ and $w_2 = \frac{1}{6}$. Then objective 1 is three times as important as objective 2, so $a_{12} = \frac{w_1}{w_2} = 3$.

To approximate w_{max} we use the following two-step procedure.

Step 1 For each of A's columns, do the following. Divide each entry in column i of A by the sum of the entries in column i. This yields a new matrix (A_{norm}) in which the sum of the entries in each column is 1. For an example of Jane's pairwise comparison matrix, the transformation from A to A_{norm} yields:

$$When\ A = \begin{bmatrix} 1 & 5 & 2 & 4 \\ \frac{1}{5} & 1 & \frac{1}{2} & \frac{1}{2} \\ \frac{1}{2} & 2 & 1 & 2 \\ \frac{1}{4} & 2 & \frac{1}{2} & 1 \end{bmatrix} then\ A_{norm} = \begin{bmatrix} .5128 & .5000 & .5000 & .5333 \\ .1026 & .1000 & .1250 & .0667 \\ .2564 & .2000 & .2500 & .2667 \\ .1282 & .2000 & .1250 & .1333 \end{bmatrix}$$

Step 2 To find an approximation to w_{max} (to be used as our estimate of w), proceed as follows. Estimate w_i as the average of the entries in row i of A_{norm}. This yields (as previously stated) $w_i = \frac{.5128+.5+.5+.5333}{4} = .5115$ for objective 1 (salary), $w_2 = .0986$ for objective 2 (quality of life), $w_3 = .2433$ for objective 3 (interest in work) and $w_4 = .1466$ for objective 4 (job location).

Averaging these numbers should give a good estimate of the percentage of total weight that should be given to the multiple objectives [Winston, 1994].

Checking for consistency
We can now use the following four-step procedure to check for the consistency of the decision maker's comparison.

Step 1 Compute Aw^T. For our example we obtain:

$$Aw^T = \begin{bmatrix} 1 & 5 & 2 & 4 \\ \frac{1}{5} & 1 & \frac{1}{2} & \frac{1}{2} \\ \frac{1}{2} & 2 & 1 & 2 \\ \frac{1}{4} & 2 & \frac{1}{2} & 1 \end{bmatrix} \begin{bmatrix} .5115 \\ .0986 \\ .2433 \\ .1466 \end{bmatrix} = \begin{bmatrix} 2.0775 \\ 0.3959 \\ 0.9894 \\ 0.5933 \end{bmatrix}$$

Step 2 Compute consistency index (CI) as follows:

$$\frac{1}{n}\sum_{i=1}^{i=n} \frac{ith entry in Aw^T}{ith entry in w^T}$$
$$\frac{1}{4}[\frac{2.0775}{.5115} + \frac{.3959}{.0986} + \frac{.9894}{.2433} + \frac{.5933}{.1466}] = 4.05 \tag{10}$$

CI $= \frac{4.05-n}{n-1} = \frac{4.05-4}{3-1} = 0.017$

Step 3 Compare CI to the random index (RI) for the appropriate value of n, given by the book "Operations Research Applications and Algorithms of Prof. Winston.

If $\frac{CI}{RI} \leq .10$, the degree of consitency is satisfactory, but if $\frac{CI}{RI} > .10$, serious inconsistencies may exist, and the AHP may not yield meaningful results [Winston, 1994].

When referring back to the first part our 8th RQ: *"Which models from literature are available to determine an optimal location for the new regional warehouse?"*, we conclude that solutions for optimal location decisions will come foreward on solving the MCDA problem.

3.5 Sensitivity analysis

Mathematical models are utilized to approximate various highly complex engineering, physical, environmental, social, and economic phenomena. Model parameters exerting the most influence on model results are identified through sensitivity analysis [Hamby, 1994].

In principle, sensitivity analysis is a simple idea: change the model and observe its behaviour. In practice there are many different possible ways to go about changing and observing the model [Pannell, 1997].

Modelers may conduct sensitivity analyses for a number of reasons including the need to determine: (1) which parameters require additional research for reducing output uncertainty; (2) which parameters are insignificant and can be eliminated from the final model; (3) which inputs contribute most to output variability; (4) which parameters are most highly correlated with the output; and (5) once the model is in production use, what consequence results from changing a given input parameter [Iman and Helton, 1998].

The simplest approach to sensitivity analysis is the one-at-a-time method where sensitivity measures are determined by varying each parameter while all others are held constant [Hamby, 1994]. Since we want to provide Vanderlande the opportunity to adjust input parameters in our model, this will be the appropriate form of sensitivity analysis in our study.

3.6 Implementation plan

An implementation plan will help identifying goals and strategies. Once the network distribution strategy is selected, it is recommended to create a road map for the implementation process. It is recommended to share the implementation plan with other department leaders to ensure that they (1) are aware of the efforts underway and (2) understand the timeline and resources that will be needed [McHugh et al., 2011].

In our solution approaches we will use the implementation plan template from the paper "Improving Patient Flow and Reducing Emergency Department Crowding" of [McHugh et al., 2011].

3.7 Conclusions

In practice, many factors have an impact on location decisions. If we are trying to determine the location of a warehouse facility in a foreign country, factors such as political stability, foreign exchange rates, business climate, duties and taxes will play an important role in decision making [Farahani et al., 2009].

When referring back to the first part our 6th RQ: *"Which models from literature are available to determine an optimal location for the new regional warehouse?"*, we conclude that solutions for optimal location decisions will come forward on taking various criteria into account. An appropriate method to use in this situation is Analytical Hierarchy Process AHP, a class within MCDA problems.

We should use Euclidean Distance with Point Facilities because Euclidian distance applies for network location problems as well as some instances involving conveyors and *air travel* [Francis and White, 1974].

In inventory modelling it can be demonstrated that under general condition, the system that minimizes the total of review, replenishment, carrying and shortage costs will be a policy member of the periodic review family [Silver et al., 2016]. However, we are not seeking for an inventory policy to minimize inventory costs, but we want to gather an estimate for managing inventory from the regional Asia-Pacific warehouse. Therefore we rather choose a policy that gives roomy costs estimates, the (s,Q) policy is the right choice.

We distinguish the decision rules of fast normally distributed items and slow distributed items by nature of determining reorder points s and fixed order sizes Q.

For Fast movers we use a normally distributed (s,Q), continuous review fixed lot size policy. For determining reorder points and order-sizes of Slow movers (poisson demand) the book "Inventory Control" of Sven Axsäter suggest to use an (s-1,s) inventory model.

4 Applying solution approaches

Using our analysis in Chapter 2, together with relevant literature of Chapter 3, we are able to find the optimal location for setting up the new warehouse facility. Furthermore we will determine the inventory allocation by using models provided by literature. By using outcomes from our inventory models and analysis on for example Lead-times, we will provide (dis)benefits on opening the new regional warehouse (RW).

4.1 Introduction to model

From literature we know that decisions on warehouse locations are commonly based on beneficial factors like e.g. Customer order Lead-time and logistics costs like transportation and warehousing costs.

Determining an optimum location is an interaction between these various criteria. When for example Stocked items are only replenished by a certain country, this is a strong reason to locate within this same country. But when costs of locating in this country are high, decisions become difficult. To solve this problem we perform multiple-criteria decision analysis after determining costs and benefits within this chapter.

In the table below we provide the MCDA matrix of our problem. This matrix illustrates the benefits and costs for alternative locations, alternative considered flow to allocate and alternative warehouse functions that are concerned with setting up a new warehouse facility. Using the AHP method, we are be able to commence decision-making between these various conflicting criteria.

As stated in the introduction (Section 1.1.3), we adopt definition for the term Distribution center and Stock-location. These terms are used to explain the specific function of the new facility. We model these differences by considering all given Order-lines or by only considering Order-lines from Stocked items.

MCDA matrix	**Criteria**	**Options**
Objective	Objective description	**Alternative options**
Costs	Transportation costs Warehousing costs Import costs Inventory costs	Alternative locations (131) Alternative warehouse functions (2) Alternative flow (3)
Benefits	Potential future sales per country Customer order Lead-time Order fulfilment from Stocked items Exchange rate stability per country Political risk index per country Dangerous goods (e.g. chemicals) Critical parts for WP&P installations	

Table 7: MCDA Analytic Hierarchy Process matrix

First we will determine costs and benefits for the above mentioned alternatives, where after we use this as input for finding the optimal location by our MCDA approach.

Because Vanderlande has relatively low replenishment sales in Asia-Pacific, we are only seeking for the location of *one warehouse facility*. To start with finding this warehouse location, we take a select set of possible warehouse locations. Because the noticed importance of a connection to distributor's and infrastructure, we will choose all metropolitan cities. The set of possible warehouse locations is added in attachment C1. As result of only having a specific set of warehouse locations, we solve a discrete modelling problem.

In applying our solution approaches we will consider several scenario's, first of all we count 131 alternative locations. Furthermore we separate two alternative warehouse functions and 3 alternative decisions on which flow to allocate to the proposed warehouse facility. Cumulative we find 786 alternatives for our AHP.

4.2 Costs estimates alternative scenarios

As described in Chapter 2 Section 2.2.2, we are able to estimate *transportation costs* for different distance ranges by using the relationship between distance, costs and weight. With opening a regional warehouse facility, there will occur (additional) *warehousing costs* as well.

We will take into account import tax duties for alternative facility locations and tax duties concerned with final delivery to customer sites. There are possibilities of importing goods only once in certain circumstances, as explained in chapter 2 section 2.4 of our study. This will result in a reduction of *import costs*.

Furthermore there are *inventory costs* involved within setting up this proposed new warehouse. We will discuss this in on of next sections, where we will built the inventory allocation model.

4.2.1 Transportation costs

As described in Chapter 2 Section 2.2.2 of this study we are able to estimate transportation costs for different distance ranges by using the relationship between distance, costs and weight. Weight of items is calculated on item level by DHL. From analysing Flow intensities in chapter 2 we know which items and quantities are transported from and to the Asia-Pacific region.

Using our transportation costs distribution we are able to estimate transportation costs of flow between both the different suppliers, the proposed regional Asia-Pacific warehouse and different customer sites.

Distances between suppliers, different warehouse locations and customers can be calculated by the central angle and earth radius (r_e=63767 in km) between two points with latitude δ_i and longitude φ_i [Tarboton, 2017] using the formula below. This is equivalent to euclidean distances, the distance used for air travelling.

$$d(\delta_1, \varphi_1, \delta_2, \varphi_2) = r \sin \delta_1 \sin \delta_2 + \cos \delta_1 \cos \delta_2 \cos(\varphi_1 - \varphi_2) \quad (11)$$

To be clear, we will not apply road distance to straight-line ratio's [Boscoe et al., 2011] for determining transportation costs. Using ratios will give to much complexity compared to the costs that will be involved. Besides transportations costs rates do not vary significantly in the lower distance ranges.

To provide insight of transportation costs as a result from alternative locations, we provide the converse relationship between inbound and outbound transportation costs *for all decomposed demand* in the illustration below. We present the alternatives warehousing functions of only maintaining a Stock-location or also adding the option to consolidate all APAC orders (Distribution center) at this new warehouse facility.

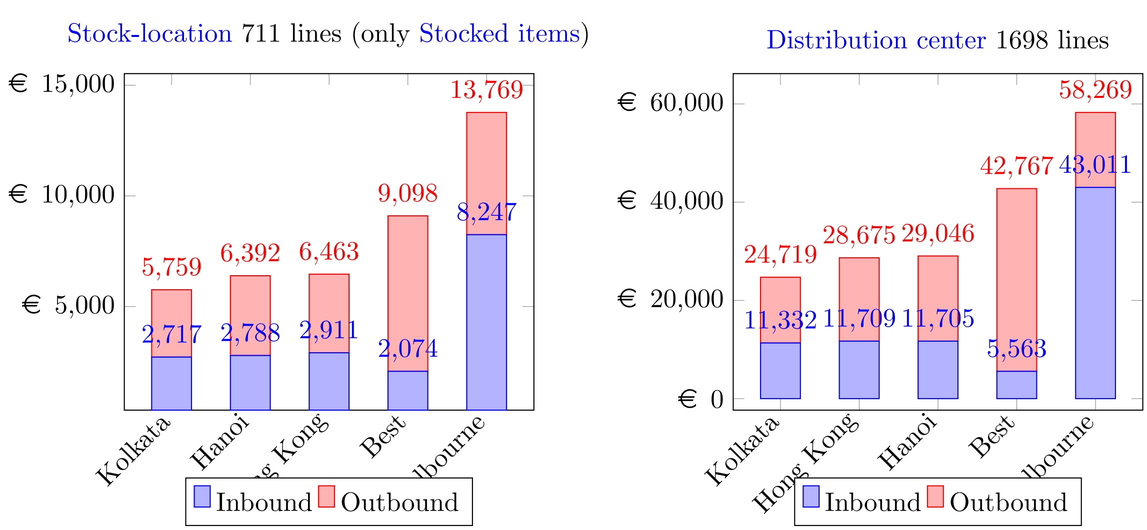

Figure 9: Transportation costs serving all demand by RW location 1 year 5 months index-year 2017

From this illustration one can quickly see that locating the regional warehouse closer to Europe, would decrease inbound costs while locating the regional warehouse closer to Australia results in lower outbound transportation costs. This is due to the high number of suppliers in the EMEA region.

For calculating transport costs for all alternative flow that could be allocated to this regional warehouse, we subdivide *demand from Asia-Pacific customer sites* and *worldwide EMEA and AMER demand from Asia-Pacific suppliers* (as introduced in chapter 2 section 2.1.2). We will estimate costs for these alternatives, while taking into account different possible warehouse functions. This will give insight in what costs will occur by alternative use of this regional warehouse. These different possible alternatives of flow allocation to the regional warehouse facility are illustrated in Figure 10 and 11 and provided in appendix A3.

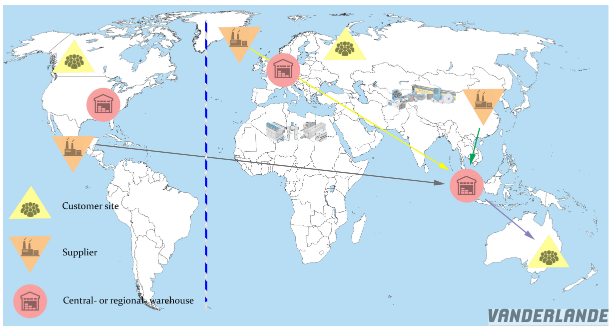

Figure 10: Serve demand APAC customers

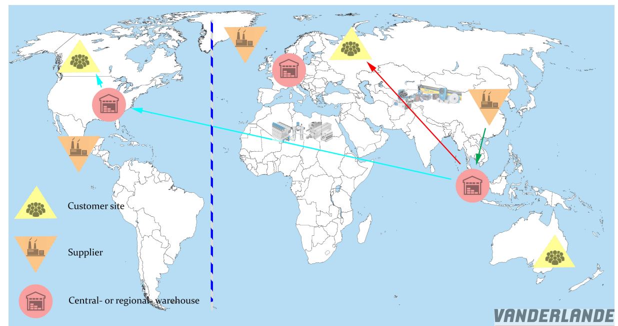

Figure 11: Serve worldwide demand APAC suppliers

Furthermore (as described in Section 2.1.2) there are *direct shipments* to Asia-Pacific customer sites, we will also consider putting the CODP of direct shipments from the suppliers to the regional warehouse. All flows considered to be managed from the regional warehouse are described in Chapter 2, Section 2.1.2.

In Table 8 below we provide the transportation cost for allocating alternative flows to alternative possible locations, only considering fulfilling orders from Stocked items at a Stock-location warehouse facility variant.

In each flow alternative we are translating the current situation of fulfilling orders by the central warehouse or by current direct delivery from suppliers into the future situation of managing these specified flows by the regional warehouse at a given warehouse location.

As clarification for alternative flow *Asia-Pacific demand*, whereas Vanderlande currently still fulfils orders by the central warehouse, we estimate transportation costs when these orders would be fulfilled at one of the facility locations instead. This refers to Figure 10 and Flow 1, 2, 3 and 4 as provided in appendix A3.

Set of locations	**All decomposed flow**	**Demand APAC customers**	**EMEA AMER demand APAC suppliers**	**All direct deliveries APAC**
Flows through RW	1-9	1-3,4	1,5-6	7-9
Orderlines		711	1371	16
Best, The Netherlands	€9.098	€6.907	€2.003	€188
Chongqing, China	€5.690	€3.437	€2.187	€65
Chengdu, China	€5.709	€3.440	€2.203	€65
Patna, India	€5.716	€3.492	€2.158	€65
Taiyuan, China	€5.717	€3.462	€2.189	€65
Xian, China	€5.717	€3.462	€2.189	€65
Suzhou, China	€5.720	€3.479	€2.175	€65
Kolkata, India	€5.759	€3.466	€2.227	€65
Chittagong, Bangladesh	€5.770	€3.452	€2.251	€65
Hong Kong, Hong Kong	€6.339	**Cheapest: €3.357**	€2.916	€65
Tokyo, Japan	€6.616	€3.429	€3.121	€65
Best, The Netherlands	€9.098	€6.907	€2.003	€188
Hong Kong, Hong Kong	(€6.339)	(€3.357)	(€2.916)	(€65)
Proposed savings	€2.758	**€3.549**	(€913)	€122

Table 8: Transportation costs alternative flow at RW for Stock-location 1 year 5 months index-year 2017

If Vanderlande would only *serve APAC demand from a specified Stock-location*, transportation costs are minimized when Vanderlande locates its warehouse in Hong Kong. Obtainable savings on transportation costs for setting up the warehouse in Hong Kong to serve APAC demand with stocked parts are €3.549 per 17 months (and €2.505 per year). Differences in (transportation) costs for all other potential locations will be provided later in this Chapter at Section 4.6, when we will calculate the total facility costs.

Because of separating alternative decisions for allocating relevant flow, we are now able to see that savings on transportation costs are results from delivering goods to Asia-Pacific customer sites *and not* by delivering goods to EMEA and AMER demand from this regional Asia-Pacific warehouse.

We see similar patterns if we consolidate complete orders from this regional warehouse (fulfil orders from Cross docking and Stocked items together: Distribution center), the results are provided in appendix B2.

It should be verified by other reasoning why it would be beneficial fulfil the worldwide EMEA and AMER demand from the proposed regional warehouse. To start Customer order Lead-time will probably increase because distances to these customer sites are shorter from central warehouse in Best.

In our supplied Excel file named "Inventory Transportation Models", one will be able to find all used methods to estimate the transportation costs above.

4.2.2 Import costs

Warehouse facility import costs can be estimated by multiplying cumulative purchasing value from certain flow with import duties rates from a proposed warehouse country location. Next to import costs for the moving goods through the warehouse facility, Vanderlande Spare Parts has to pay import duties for importing spare parts from the warehouse facility to countries of final delivery (the customer sites).

For estimating import tax costs of new regional warehouse locations, we use the table for rates per country given in chapter 2 section 2.4. Next to these rates, we assumed that import tax rates from the regional warehouse to customer sites are 5% for all different countries. There is limited information available about internal import duties in Asia-Pacific countries.

In the table below we provide import costs for *serving Asia-Pacific demand*, that would occur in 1 year and 5 months (starting in 2017). For the other two flow alternatives we were not able to determine import costs due to unavailable information of tariffs for importing goods from Asia-Pacific countries.

			Purchasing value		Total import tax paid	
Alternative	**Facility tariffs**	**Final customer tarrifs**	**Stock-location**	**Distribution center**	**Stock-location**	**Distribution center**
Order-lines			711	1698	711	1698
AU	2%	5%	€ 154.289	€ 437.312	€ 4.510	€ 16.974
BN	0%	5%	€ 154.289	€ 437.312	€ 7.710	€ 21.861
CN	4%	5%	€ 154.289	€ 437.312	€ 13.636	€ 38.271
HK	0%	5%	€ 154.289	€ 437.312	€ 7.547	€ 19.339
ID	7.5%	5%	€ 154.289	€ 437.312	€ 18.742	€ 52.949
IN	5%	5%	€ 154.289	€ 437.312	€ 15.424	€ 43.345
KH	0%	5%	€ 154.289	€ 437.312	€ 7.666	€ 21.328
MM	5%	5%	€ 154.289	€ 437.312	€ 7.714	€ 43.372
PH	1%	5%	€ 154.289	€ 437.312	€ 1.542	€ 26.233
SG	0%	5%	€ 154.289	€ 437.312	€ 7.617	€ 21.591
J	0%	5%	€ 154.289	€ 437.312	€ 7.714	€ 21.866
TH	3%	5%	€ 154.289	€ 437.312	€ 12.341	€ 34.943
TM	2%	5%	€ 154.289	€ 437.312	€ 10.644	€ 30.086
TW	5%	5%	€ 154.289	€ 437.312	€ 7.714	€ 43.467
VN	0%	5%	€ 154.289	€ 437.312	€ 7.562	€ 21.427
NL	0%	5%	€ 154.289	€ 437.312	€ 7.714	€ 21.865

Table 9: Import tax 1 year 5 months index-year 2017 of serving APAC demand alternative RW locations

Import costs are minimal when Vanderlande would locate a regional warehouse in Australia. *This because in Australia, for most import value, Vanderlande has to pay import duties only once.* If one is interested, in appendix B3 we added information about the derivation of facility and final customer import costs.

Because of making strong assumptions on import duties for importing spare parts from the warehouse facility to countries of final delivery, we will provide the opportunity to perform sensitivity analysis on our model. This will be discussed in later stage of this study.

4.3 Inventory allocation model

In this section we provide inventory advise for alternative use of the proposed Asia-Pacific warehouse. First we discuss demand classification where-after we will give implemented inventory policies and costs.

4.3.1 Proposed demand classification

As stated in Chapter 2 in Section 2.5.1 of this study, decisions on what item to keep on stock are defined by the following logistical parameters:

1. A replenishment part should be replenished last 24 months, with 4 months of customer-orders.
2. A replenishment part should be replenished last 12 months, with 2 months of customer-orders.

Since we only used the transaction data of 1 January 2017 until 31 May 2018 we adjust the first logistical parameter to a minimum of 3 months demand.

Similar as calculating transportation costs with different alternatives of flow allocation, we subdivide *demand from Asia-Pacific customers* and *worldwide demand from Asia-Pacific suppliers* and *direct delivery.*

For each of above given alternatives we calculate the number of stock keeping items by the logistics parameter, as given above. These items are considered as Stocked items for our regional Asia-Pacific warehouse.

As described in our literature review we distinguish Fast- and Slow- movers by the average number of periods between demand events ($p \leq 1.18$) and the average demand sizes ($ds \leq 2$). In the table below we provide the number of Fast- and Slow- movers by using the logistical parameters.

Parameters	All decomposed flow	Repl. parts demand APAC	EMEA AMER demand APAC suppliers	All direct deliveries APAC	Packages demand APAC
Flows through RW	1-9	1-3,4	1,5-6	7-9	1-3,4
1. last 24mnths	266	147	113	6	314
2. last 12mnths	306	148	127	31	783
# Stocked items	215	110	105	3	307
Fast movers	10	0	10	0	0
Slow movers	205	110	95	3	307

Table 10: Stock keeping items at regional warehouse (RW)

When comparing a total of 215 items (from which 105 for APAC customer sites demand) to be kept on stock in the regional Asia-Pacific warehouse with 2.497 items that are kept on stock in the central warehouse, we conclude that the proposed warehouse facility will be relatively small.

Within these 105 items there are also critical components represented. This will form extra ability to deliver better service to the customer sites in the Asia-Pacific region. Information about criticality of Stocked items by our demand classification is provided in appendix B14.

Only fulfilling demand from EMEA and AMER at the proposed warehouse facility, will generate 10 Fast movers. Inventory hold for serving Asia-Pacific customer sites will consist of 110 Slow movers.

Since we only consider replenishment sales in our inventory advise, and besides, Packages sales represented €4.1 million of total APAC sales, it is also relevant to check whether Vanderlande does not sell Fast movers in their Packages demand. However, as can be seen in the table above, this is not the case.

In contradiction to that Vanderlande maintains stock out probabilities for their decision rules, we will use fill rates in ours. Because we want to have roomy inventory estimates, and demand or lead time variability for Asia-Pacific demand is high, the right measures for estimating safety stocks are fill rates $P2$.

4.3.2 Proposed forecasting

As stated in the analyse phase of this research paper, the vast majority of items are calculated based on only demand class and live cycle. Selling spare parts is not depending on external factors like seasonality.

Therefore we calculate the standard deviation daily demand forecast of each item simply by dividing the yearly demand by 365 days and standard deviation of yearly demand by $\sqrt{\sigma_{yr}} * \sqrt{1/365}$.

Standard deviation of yearly demand is calculated using the standard deviation function in Excel with demand per item over period 1 january 2017 until 31 may 2018.

4.3.3 Inventory policies

As stated in our literature review we will only evaluate the (s,Q) policy. From literature we know that different demand classifications ask for different inventory models, *Fast movers require a normal distribution* while replenishment advises of *Slow movers are usually determined using a poisson distribution.*

In determining reorder points and order sizes for our Asia-Pacific warehouse inventory, we made the assumption that Supplier Lead-time for product supply will become 5 days longer due almost all suppliers are still stationed in Europe and transit-times to Asia-Pacific are approximately 5 days.

Fast-moving (normally distributed) inventory
Provided by the book of Silver, Pyke and Thomas, reorder point s of a normally distributed (s,Q) inventory model is determined by:

$$s = x_L + \text{k} * \sigma_L \tag{12}$$

We can derive k for the safety stocks from the value of $G(k)$, using Fill rate $P2$ for each item.

Next to reorder point s we calculate order sizes Q of each stocked item from the decisions rules of the (s,Q) inventory policy. Decisions rules for determining the required order sizes, on hand stock and total relevant yearly inventory costs are provided in our literature review.

To give an example about how we came to replenishment advise for fast moving inventory, we give an example below of a few Fast movers kept on stock for EMEA and AMER demand from APAC suppliers.

Item-number	ABC-Class	v(€)	Lead-time	D	k	σ_L	SS	SS(€)	s	Q	On hand stock	On hand stock(€)	TRC(Q+SS)
002763-00010	A	0.025	22	2309	1.645	67	112	2.83	258	2962	1593	38.82	18.01
005303-00543	A	125.49	22	34.58	1.645	0.59	1	125.49	4	6	4	501.98	156.93
005510-00438	A	203.77	22	316.23	1.645	5.45	9	1833.98	29	13	15.5	3158.52	598.85
006002-14450	A	8.57	8	394.58	1.645	3.77	7	60.00	17	67	40.5	347.18	136.94
006002-14491	A	28.5245	15	165.88	1.645	1.86	4	114.09	12	24	16	456.39	161.98
...													

Table 11: Replenishment advice fast movers EMEA AMER demand APAC suppliers via RW

In appendix B6, B7 and B8 we give replenishment advise for all stocked items. B5 refers to replenishment advise for *Asia-Pacific demand* and B6 for *EMEA and AMER demand from APAC supply.*

Slow-moving (poisson distributed) inventory

As stated in the literature review, there are methods to determine slow-moving inventory. Under condition of high number of periods between demand events ($p \leq 1.18$) *and* low mean demand sizes ($ds \leq 2$), we can distinguish slow-moving demand from fast-moving demand. Since the vast majority (80%) of items considered as slow-moving demand (by periods between demand events p) also characterize low average demand sizes ds, we are only interested methods from poisson demand inventory modelling.

Given the literature of the book of [Axsäter, 2015], we are able to determine reorder points and order-sizes of poisson demand using an (s-1,s) inventory model. In case of Poisson demand we are able to determine s by the following formula below.

$$P2 = \sum_{n=0}^{s-1} \frac{(DT)^n * e^{DT}}{n!} \tag{13}$$

Decision variables:

- s = stock level: total amount in repair and distribution

- $P2$ = fill rate, fraction of demand satisfied without delay
- DT = Demand during Supplier Lead-time

Fill rate:
- Demand is one by one
- Fill if at least one item in inventory, in other words at most s-1 items in repair [Axsäter, 2015]

In the table below we give an example of the replenishment advise for a few Slow movers considered to be kept on stock for demand from Asia pacific customer sites.

Item-number	ABC	Leadtime	v(€)	D	T(year)	DT	s	Q	On hand stock	On hand stock(€)	TC(Q)	$P2$,Q=1	P2,Q=2
001019-002-00090	C	22+5	3.22	11.29	$\frac{27}{365}$	0.83	2	3	3	9.66	45.22	0.43	0.79
001019-002-00133	C	22+5	4.99	7.05	$\frac{27}{365}$	0.52	1	2	2	9.98	41.96	0.59	0.90
001019-002-00176	C	22+5	5.29	7.76	$\frac{27}{365}$	0.57	1	2	2	10.59	46.11	0.56	0.88
001019-002-00220	C	22+5	5.61	7.76	$\frac{27}{365}$	0.57	1	2	2	11.22	46.18	0.56	0.88
001019-002-00306	C	22+5	5.88	8.47	$\frac{27}{365}$	0.62	1	2	2	11.71	50.32	0.53	0.86
...													

Table 12: Replenishment advice slow movers APAC customer demand from RW

In appendix B6, B7 and B8 we give replenishment advise for all stocked items. B5 refers to replenishment advise for *Asia-Pacific demand* and B6 for *EMEA and AMER demand from APAC supply*. B7 refers to replenishment advise for *direct shipped Asia-Pacific demand*.

Furthermore we refer to the supplied Excel spreadsheet "Inventory Transportation Models" for more profound understanding of our inventory allocation model.

4.3.4 Inventory costs for warehouse facility

Considering the different approaches for determining fast or slow moving inventory in the proposed regional warehouse, we present total relevant yearly inventory costs and total value of inventory held on stock that will occur with opening this new warehouse facility.

Demand type	All decomposed flow	Flow demand APAC customers	EMEA AMER demand APAC suppliers	All direct deliveries APAC
Flows through RW	1-9	1-3,4	1,5-6	7-9
Total On hand stock(€)	€108.760	€53.726	€54.188	€846
Total relevant costs(€)	€24.967	€12.296	€12.037	€634

Table 13: Total value and total yearly relevant costs of stock keeping items at RW index-year 2017

As can be seen in the table above, total value of inventory hold on stock for the Asia-Pacific demand is €53.726. If we put the CODP of direct deliveries to Asia-Pacific customers from suppliers towards the proposed warehouse, we have to count for holding an extra €846 of inventory value at the new facility.

This all says something about the capital intensity of items that will be kept on stock. Still however, a lot of these items are considered as items with a high Criticality. By this Vanderlande will deliver beneficial service in terms of availability of Criticality parts for customer sites in the Asia-Pacific region.

4.4 Warehousing costs

As described in Chapter 2, Section 2.3, warehousing costs for small public warehouses are usually driven by throughput rates and storage space costs.

By using the result of the inventory requirements on the different alternatives from our inventory model in last section, we are able to determine the cubic metre of space required for all parts together. If Vanderlande only serves Asia-Pacific customer sites with the proposed warehouse, the $0.82m^3$ of space required in the regional warehouse is minimal. When we allocate all specified flows to the regional Asia-Pacific warehouse, the ($5m^3$) of required space for the warehouse is a bit more significant. Just to give an indication, the central warehouse needs space for around $807m^3$ of parts (provided in section 2.3).

Dependently on flow to allocate to the new regional warehouse, we calculate the required storage space by designating sizes of items to specified groups. First large items will use pallet space, furthermore we will use pallet box stacking for medium items and groups of similar smaller items. For small unique items we will allocate to a shelf rack. We have capacity for 1 pallet on a pallet space, 12 box pallets on a box stacking spot and 80 small boxes of unique items in a shelf rack.

In Table 14 below we provide the required storage components and sizes for all different alternatives.

Flow allocation	**Pallet space** (m^2)	**Box-stacking space** (m^2)	**Shelf space** (m^2)
Flow demand Asia-Pacific customers	1	4	1
Worldwide demand from Asia-Pacific suppliers	7	3	1
All direct delivery through RW	0	0	1
All decomposed flow through RW	8	7	2

Table 14: Required storage size new warehouse facility

From the table one will notice that worlwide EMEA and AMER demand from Asia-Pacific suppliers requires far more storage space than storage space as result from Asia-Pacific demand. This is especially interesting because we approximately count the same amount of Order-lines for both alternatives. From here we can conclude that *holding stock for Asia-Pacific customer sites takes relatively little storage space.*

Using the throughput rates per Order-lines and storage space costs per m^2 from section 2.3, we are able to estimate warehousing costs for all alternative possible functions of the proposed regional warehouse. In the illustration below we give storage and throughput costs for different possible warehouse locations when the regional warehouse would *only serve Asia-Pacific customer sites.*

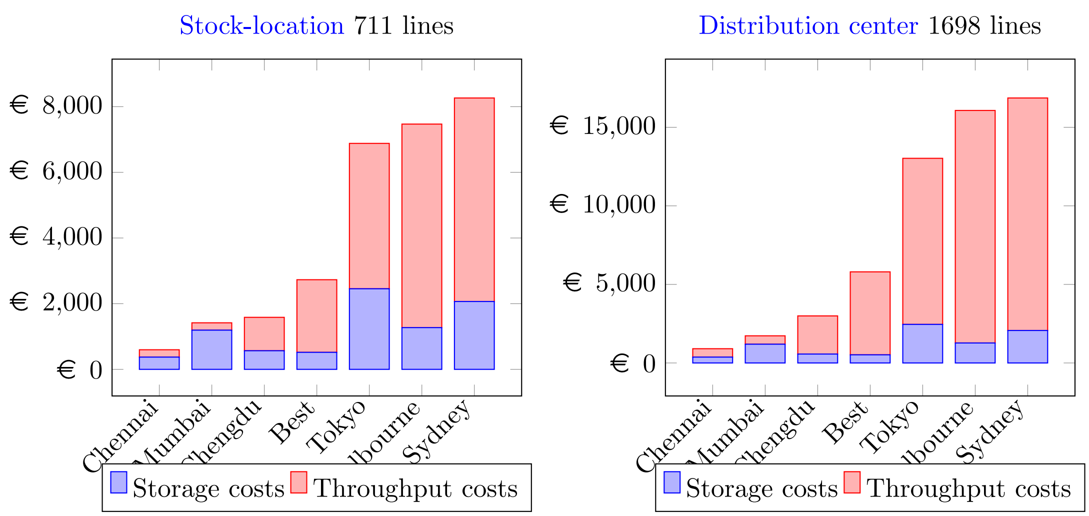

Figure 12: Storage and throughput costs serving APAC demand by RW 1 year 5 months index-year 2017

In appendix B4 and B5 we provide storage and throughput costs for allocating the other alternative flows to the regional warehouse. One will notice that holding stock for EMEA and AMER demand from Asia-Pacific supply takes relatively large storage space and so storage costs, supporting previous statement.

Locating the new regional warehouse in for example China or India will reduce warehousing costs, because of low throughput rates and storage costs in certain countries. We notice large differences in warehousing costs as result of alternative countries, because throughput rates and storage costs of countries are indexed by using GDP per capita (derivation is provided in section 2.3).

In our supplied Excel file named "Warehousing Models", one will find all methods used to estimate the warehousing costs above. Because of making strong assumptions for estimating storage and throughput rates, we provide the opportunity to perform sensitivity analysis on our model. This will be discussed in chapter 5.

4.5 Potential Asia-Pacific

Based on financial accounting data of replenishment sales between 2015 and 2017 we forecasted linear spare part sales growth per customer site, industry, country and regional country zone. In the included Excel spreadsheet "Forecasting Models" we provide our replenishment sales forecasting model. In the table below we provide the replenishment forecast per industry and country of the Asia-Pacific region.

This table is removed for publication.

In financial year's 2018, 2019 and 2022 we forecast percentual growth of 117, 126 and 150% respectively for all customer sites among the world. This can be used to calculate future facility costs estimates.

Equivalent to the statement in chapter 2 that most sales is from Australian WP&P customer sites, this is also expressed in our forecast. This indicates that *based on future sales it is beneficial to locate in Australia.*

Potential sales forms input to our MCDA model in further stage of this study. Countries with significant future replenishment sales should rated higher in our MCDA then countries with no potential sales.

4.6 (Future) warehouse facility costs

After the derivation of all relevant costs, we are now be able to determine an optimum warehouse location from *costs perspective.* For each location and alternative warehouse function, we add all the following costs elements for estimating costs that will occur when Vanderlande would open a warehouse facility: transportation costs (Tc), warehousing costs (Wc), import duties (Dc) and inventory costs (Ic).

In the illustration below we give all relevant costs for setting up a new regional warehouse in the Asia-Pacific region to *serve Asia-Pacific demand.* Again we make division between costs that will occur when the regional warehouse functions as Stock-location or as a Distribution center.

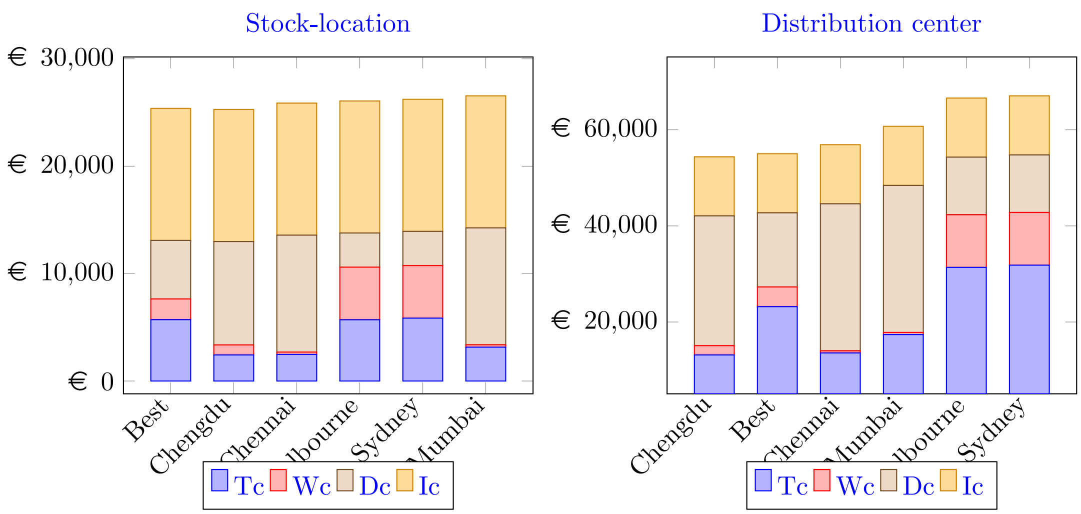

Figure 13: Yearly costs for serving APAC demand by alternative RW location index-year 2017

Warehousing costs varies between countries like for example China or Australia. On the other hand *import costs are far less in Australia.* Due these contradictory impacts on different costs components by alternative locations choices, we notice that cost estimations are levelling out to a certain point.

In appendix B9 we provide illustration of all costs components for adding other relevant flow to the new warehouse facility, namely: *serving EMEA and AMER demand from Asia-Pacific suppliers* and *serving direct shipments to APAC customers.* For these two alternatives we were not able to determine import costs due to unavailable information of tariffs for importing goods from Asia-Pacific countries.

In Table 15 we provide the yearly costs for the different alternatives. Estimation's of obtainable savings are provided in appendix B10.

We can calculate savings by subtracting facility costs for each candidate location by costs that occurs when we would maintain current warehouse structures (namely, serving demand by the central warehouse).

APAC demand	**Stock-location**					**Distribution center**				
Set Locations	Tc	Wc	Dc	Ic	*Tot*	Tc	Wc	Dc	Ic	*Tot*
Best, Netherlands	€4.876	€1.927	€5.445	€12.296	€24.544	€23.201	€4.094	€15.434	€12.296	€55.025
Bangkok, Thailand	€2.413	€702	€8.712	€12.296	€24.122	€13.020	€1.446	€24.666	€12.296	€51.427
Shenzhen, China	€2.370	€931	€9.626	€12.296	€25.223	€12.544	€1.928	€27.015	€12.296	€53.783
Kolkata, India	€2.447	€220	€10.888	€12.296	€25850	€13.335	€439	€30.597	€12.296	€56.667
Melbourne, Australia	€5.704	€4.891	€3.184	€12.296	€26.076	€31.360	€10.964	€11.982	€12.296	€66.602
Mumbai, India	€3.150	€220	€10.888	€12.296	€26.554	€17.385	€439	€30.597	€12.296	€60.717
Medan, Indonesia	€2.400	€432	€13.230	€12.296	€28.357	€13.629	€866	€37.376	€12.296	€64.168
Best, Netherlands	€4.876	€1.927	€5.445	€12.296	€24.544	€23.201	€4.094	€15.434	€12.296	€55.025
Bangkok, Thailand	€2.413	€702	€8.712	€12.296	€24.122	€13.020	€1.446	€24.666	€12.296	€51.427
Savings for Bankok	€2.463	€1.225	(€3267)	€0	€422	€10.182	€2.648	(€9232)	€0	€3.598
All decomposed flow	**Stock-location**					**Distribution center**				
Set Locations	Tc	Wc	Dc	Ic	*Tot*	Tc	Wc	Dc	Ic	*Tot*
Kolkata, India	€4.065	€652	€10.888	€24.967	€40.572	€17.449	€1.025	€30.597	€24.967	€74.037
Bangkok, Thailand	€4.821	€2.078	€8.712	€24.967	€40.578	€21.269	€3.344	€24.666	€24.967	€74.246
Chengdu, China	€4.030	€2.759	€9.626	€24.967	€41.382	€20.305	€4.454	€27.015	€24.967	€76.741
Best, Netherlands	€6.423	€5.704	€5.445	€24.967	€42.539	€30.188	€9.389	€15.434	€24.967	€79.979
Jakarta, Indonesia	€9.976	€1.280	€13.230	€24.967	€49.452	€43.486	€2.019	€37.376	€24.967	€107.848
Melbourne, Australia	€9.720	€14.459	€3.184	€24.967	€52.330	€41.131	€24.789	€11.982	€24.967	€102.870
Singapore, Singapore	€8.866	€16.423	€5.377	€24.967	€55.633	€40.102	€27.504	€15.241	€24.967	€107.815

Table 15: Yearly costs regional warehouse by alternative flow, location and function index-year 2017

From the tables in appendix B10, presenting estimations for the alternative options, one will notice that *there are savings to obtain in with certain alternative warehouse and location decisions.*

Out of cost perspective it could be interesting to either fulfil Asia-Pacific demand or worldwide EMEA and AMER demand from this new facility. Unfortunately, this is only restricted to certain *unattractive warehouse locations from political perspectives.* However, additional costs will never become significant.

The main conclusions we make is that establishment climate of western countries will provide benefits on import costs and emerging economies will result in low warehousing costs. Perspectives on costs support that *motivation on where to locate the new warehouse facility should come from service perspective* only.

4.6.1 Future facility costs

Future projection of costs can be expressed by assuming linear growth. For transportation, warehousing and import costs we simply multiply costs estimated for 2017 by given percentual growth of forecasted replenishment sales to get future costs estimates. However for future inventory costs we use same calculation methods as for determining inventory cost in our inventory model. In appendix B11 we provide future costs for setting up a new regional warehouse for alternative warehouse functions and locations.

Due to alternatively high import costs or transportation and warehousing costs *we make future prognosis of only increasing costs over the next 5 years for all politically relevant warehouse locations.* No break-even point can be achieved now or in (longer) future with setting up this new warehouse facility.

Sourcing in Asia-Pacific countries will result in lower transportation costs and inventory costs. This might be sufficient to suppress the higher import costs for importing goods from surrounding countries to the proposed warehouse location. If Vanderlande would source spare parts in Australia or China, import costs will be zero for a large part of the given import value. In this scenario, cost reduction will become realistic.

4.7 Benefits

Given (dis)benefits from analyses and literature in previous chapters, we will be able to provide effects that would support or withhold opening a regional warehouse facility at one of our candidate locations.

4.7.1 Order fulfilment

Based on historical sales data we verified how many spare part orders Vanderlande would fulfil with inventory kept on stock at the proposed new warehouse facility.

In the figure below we provide an illustration of historical orders that could be fulfilled from Stocked items, together with a representation of Order-lines per industry. We only provide order fulfilment of *demand from Asia-Pacific customer sites.*

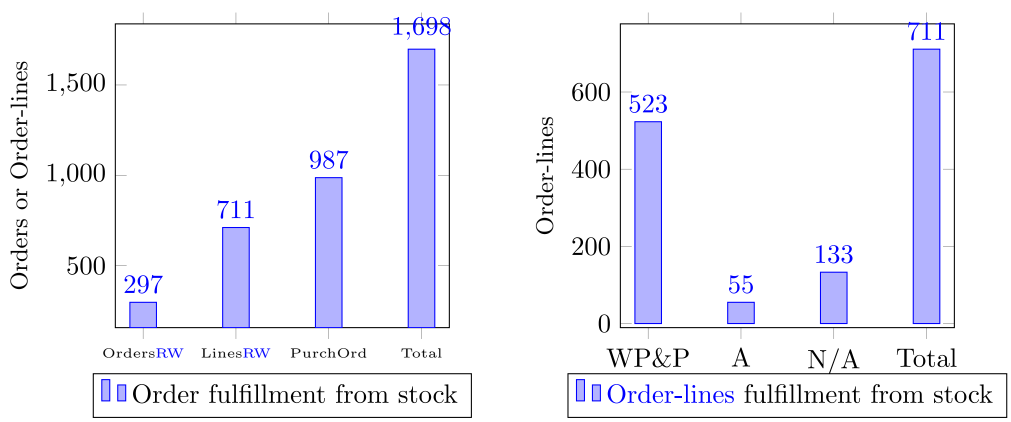

Figure 14: Order fulfilment Repl. parts from serving APAC demand between 01-01-17 - 31-05-18

One will notice that a large amount (711) of the total (1698) Order-lines for APAC customer sites could be fulfilled from stock at the proposed warehouse. Most of these Order-lines are meant for WP&P sites.

Furthermore we verified fulfilment of orders by the regional warehouse for *EMEA and AMER demand*. More information is provided in appendix B12. Orders do not directly represent sales, therefore we translated sales from order-fulfilment in appendix B13.

Another important decision on where to set up the proposed warehouse, is *countries of customer sites that Vanderlande will serve with inventory kept on stock*. In the graph below we illustrate the relative percentage of Order-lines directly fulfilled by the regional warehouse, represented by the different countries.

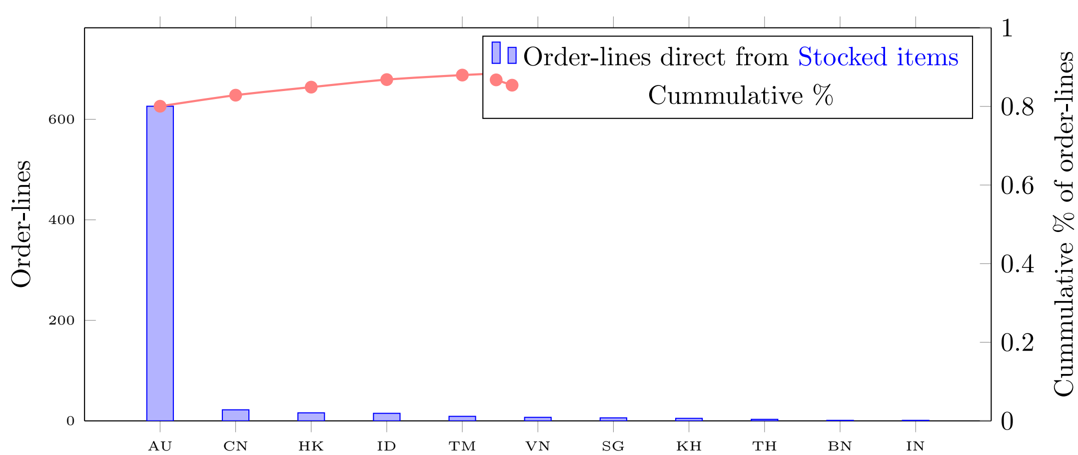

Figure 15: Order-line fulfilment Repl. parts from serving APAC demand between 01-01-17 - 31-05-18

From the graph, we can conclude that *Australia represents approximately 80% of the Order-lines (and 80% sales) that can be fulfilled from stock at the proposed regional Asia-Pacific warehouse.* Of these 80% of Australian Order-lines from stock items, almost all Order-lines are meant for WP&P customer sites.

All Australian WP&P customer sites this sentence is removed for publication are located in Melbourne. From service perspectives, when setting up the new warehouse facility, we would therefore strongly advise to place this regional warehouse close to these Australian WP&P customers sites.

Because Vanderlande has multiple large WP&P customers by Replenishment parts usage, it is not interesting for Vanderlande Spare Parts to put local Consignment stock at all different Australian WP&P sites.

When again referring to our 11th RQ *"How could we improve optimal sourcing for customer sites considering different alternatives considering growth path in the Asia-Pacific region?"*, *from perspective on order fulfilment of Stocked items, we should locate our regional Asia-Pacific warehouse in Melbourne.*

4.7.2 Lead-times

It is clear that Customer order Lead-time are longer for customer sites in Asia-Pacific than other regions. As stated in chapter 2 section 2.6.2. we have to count for 10 days longer Customer order Lead-time then average Customer order Lead-time from all different country regions together. We need to find causes of long Lead-times to determine how much advantage Vanderlande's customer sites could obtain from setting up the regional warehouse to *serve Asia-Pacific demand.*

In Table 16 we illustrate possible *average Lead-time reduction in days to Asia-Pacific customer sites* when Vanderlande would locate the warehouse facility at one of the candidate possible country locations.

Cause of long Lead-time	**HK**	**SG**	**TW**	**AU**	**JP**	**NL**	**TH**	**IN**	**CN**	**ID**	**PH**	**VN**	**KH**	**BN**	**MM**
Forwarding in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Security clearance	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0
Document issuance	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0
(Air) transport	2	2	2	3	2	0	2	2	3	2	2	2	2	2	2
Customs clearance arrival	0	0	0	3	0	0	0	0	1	0	0	0	0	0	0
Item delivery (road)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
APAC Lead-time	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Obtainable Lead-time reduction	(2)	(2)	(2)	(10)	(2)	(0)	(2)	(2)	(6)	(2)	(2)	(2)	(2)	(2)	(2)
APAC Lead-time by new facility	28	28	28	20	28	30	28	28	24	28	28	28	28	28	28

Table 16: Customer order Lead-time reduction to APAC customers by alternative RW country location

First of all we expect a Lead-time reduction for air travel. Given the transit times by the data base of [SeaRates.com, 2018], Vanderlande saves 2 days on air travel from most candidate warehouse locations.

However, for Australia and China we expect more time reduction because a large part of Order-lines are sent to destinations within same country. In this situation air travel time will become minimal.

Because the destination of certain orders are similar to the country of the proposed warehouse location, we expect that there is less time required for security clearance and customs arrival clearance. If Vanderlande would set up the regional warehouse in Australia, Customer order Lead-time due to clearing goods before shipping and at arrival to customer sites will become null for a significant amount of orders.

If we come back to our 10th RQ: *"What benefits will come forward on locating a new warehouse in the Asia-Pacific region?"*, based on ability to timely deliver parts to Asia-Pacific customer sites, Vanderlande should locate its warehouse in Australia. Timely availability of spare parts at customer sites is important since systems downtime may have serious consequences.

By controlling the supply of spare parts in Asia-Pacific region via a warehouse facility in Australia, Vanderlande will execute its mission statement for customer sites in this region. Customer order Lead-time of replenishment parts is a critical factor for the customer's system uptime.

As input for our MCDA model we assume that *serving EMEA and AMER demand from APAC supply* by the new warehouse facility will increase Customer order Lead-time to these customer sites with 5 days.

Furthermore we expect 10 days on Customer order Lead-time reduction by opening a warehouse facility that fulfils all Asia-Pacific orders (when the warehouse functions as Distribution center). We expect these significant Lead-time reduction because Vanderlande Spare Parts will be able to consolidate complete Asia-Pacific orders from Stocked items and e.g Cross docking together.

4.7.3 Dangerous goods

As stated in Chapter 2, Section 2.6.5, orders containing Dangerous goods increase Customer order Lead-time. Now we learned that most inventory on stock is meant to for Australian WP&P customers, it would be relevant to know which partition of Dangerous goods is from demand of Australian WP&P customer sites.

Because the vast majority Order-lines do not consist of Dangerous goods and Customer order Lead-time also depends on various other factors, we can not translate the impact Dangerous goods to average Lead-time in days to each country within the Asia-Pacific region. We therefore will just take into account how many Dangerous goods went to all different countries for determining an optimal location.

In Table 17 below we provide the representation of Flow intensities of Dangerous goods going to Asia-Pacific countries. Flow intensities refers to number of pieces sold among all different items.

Only once, we take Packages demand into account. This because also within Packages sales, unavailability of Dangerous goods in certain countries causes a significant Customer order Lead-time escalation.

Country	**HK**	**SG**	**TW**	**AU**	**JP**	**NL**	**TH**	**IN**	**CN**	**ID**	**PH**	**VN**	**KH**	**BN**	**MM**
DG Repl. parts flow	0	0	0	0	0	0	0	5	20	0	0	0	2	0	0
DG Packages flow	0	0	0	46	0	0	0	0	1	0	0	0	2	0	0
DG flow in Asia-Pacific	0	0	0	46	0	0	0	5	21	0	0	0	4	0	0
DG Order-lines	0	0	0	5	0	0	0	1	2	0	0	0	2	0	0
DG Repl. parts sales	0	0	0	0	0	0	0	€ 263	€ 1.282	0	0	0	€ 75	0	0
DG Packages sales	0	0	0	€ 19.331	0	0	0	0	€ 89	0	0	0	€ 75	0	0

Table 17: Flow intensities of Dangerous goods towards Asia-Pacific countries 01-01-17 - 31-05-18

By this illustration, we conclude that *most of Packages orders consisting Dangerous goods are meant for Australian sites*. This gives extra motivation why Vanderlande should set up the warehouse in Australia.

4.7.4 Criticality Asia-Pacific customer sites

As noticed in Chapter 2, Section 2.6.6, from the total 1.016 Order-lines sent from the central warehouse towards WP&P customers in the Asia-Pacific region, 439 Order-lines are considered as parts with high Criticality. This is a representation of parts from an installations sorting system.

Even more interesting is how much of these specified WP&P Criticality parts are kept on stock by use of our inventory model. Of the total 523 WP&P Order-lines that are delivered directly from stock to APAC customer sites, 270 are considered to be highly critical. This means that relatively, we can fulfil half of these critical items orders from stock. We added analysis of stocked criticality items in appendix B14.

In the table below we provide Order-lines of Criticality parts going to Asia-Pacific countries.

Country	**HK**	**SG**	**TW**	**AU**	**JP**	**NL**	**TH**	**IN**	**CN**	**ID**	**PH**	**VN**	**KH**	**BN**	**MM**
Criticality Order-lines	43	7	0	339	0	0	4	2	21	8	0	5	9	1	0

Table 18: Flow intensities of Criticality parts towards Asia-Pacific countries 01-01-17 - 31-05-18

If we come back to our 10th RQ: *"What benefits will come forward on locating a new warehouse in the Asia-Pacific region?"* , based on ability to timely deliver Dangerous goods and Criticality parts, Vanderlande should locate the warehouse in Australia. When Vanderlande would keep all critical and dangerous items on stock at the new regional warehouse, inventory and warehouse costs will logically increase.

4.8 Multiple-criteria decision analysis

In previous stated (sub)conclusions of this study we noticed that Melbourne has multiple benefits from for example order fulfilment from Stocked items, Customer order Lead-time and Criticality parts. In addition, most Asia-Pacific growth is projected at Australian WP&P customer sites. However, as provided in Section 4.6, costs for setting op a facility in Melbourne are a bit more significant then other candidate locations.

We will apply MCDA to make sure we form strong ground for our recommendations between the warehouse location and alternative trade-offs by facility costs, potential sales and benefits.

4.8.1 Approach

By earlier motivation of our literature review, we will use the Analytical Hierarchy Process (AHP) type of MCDA problems to solve our problem. In Figure 16 we present the structure of all elements in criteria, sub-criteria and alternatives. This forms input to our AHP model.

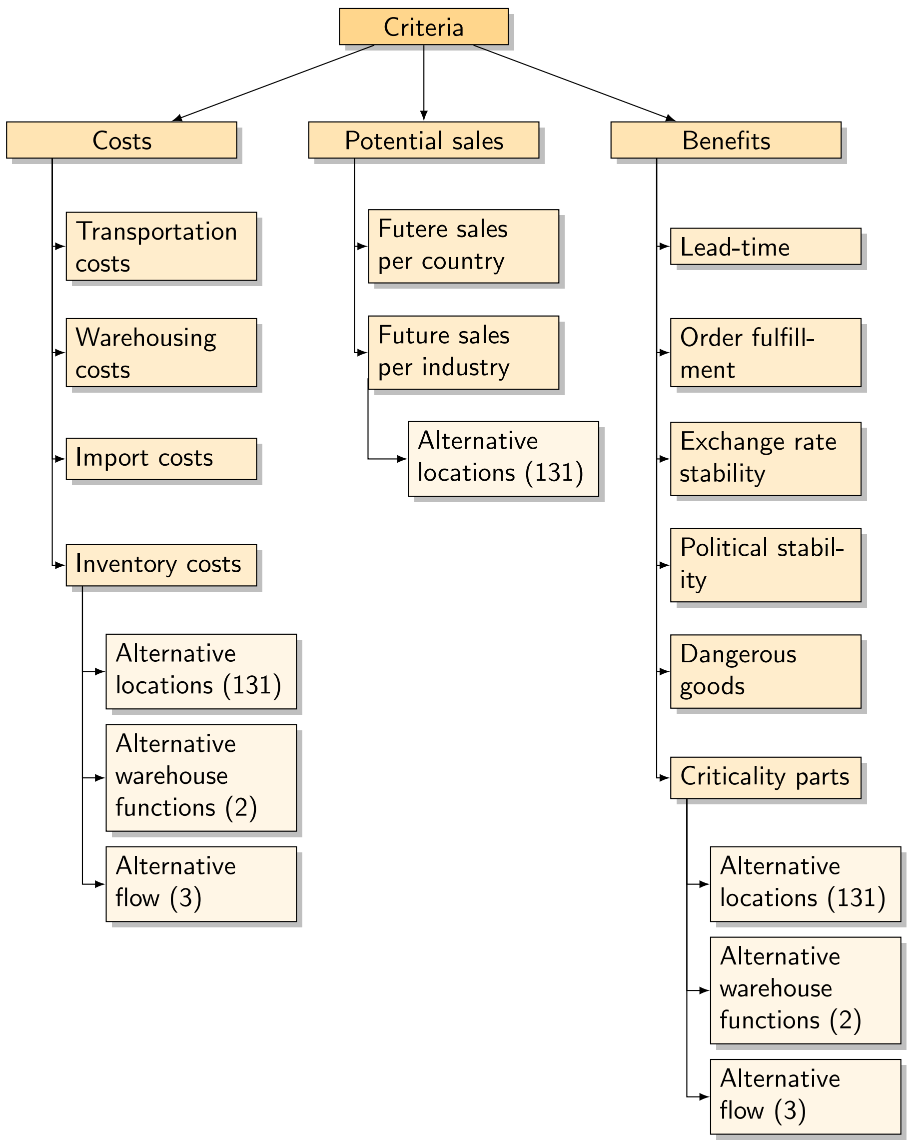

Figure 16: Structure elements in criteria, sub-criteria, alternatives etc.

As illustrated above, our objectives are costs, (dis)benefits from opening a new warehouse and potential sales at a given country of different possible warehouse locations.

By following the AHP procedure together with multiple managers within Vanderlande, we obtain *weights for each objective*. In appendix B15 we provide the prioritization of multiple managers.

To find w_{max} we use the two-step procedure of [Winston, 1994], as provided in our literature review. We will start analysing weight for objectives given the prioritization of Frank van Schijndel, the department manager of Vanderlande Spare Parts. We compare all elements pair wise with respect to the objective.

Step 1 For each of A's columns, we divide each entry in column i of A by the sum of the entries in column i. This yields a new matrix (A_{norm}) in which the sum of the entries in each column is 1.

$$\text{When A} = \begin{array}{c} \\ Costs \\ Potential \\ Lead-time \\ Fulfilment \\ Exchange \\ Political \\ DG \\ Criticality \end{array} \begin{array}{c} \begin{array}{cccccccc} Costs & Potential & Lead-time & Fulfilment & Exchange & Political & DG & Criticality \end{array} \\ \begin{pmatrix} 1 & \frac{1}{4} & 1 & \frac{1}{3} & 8 & \frac{1}{8} & \frac{1}{5} & \frac{1}{2} \\ 4 & 1 & \frac{1}{5} & \frac{1}{5} & 6 & \frac{1}{8} & \frac{1}{8} & 5 \\ 1 & 5 & 1 & 1 & 4 & \frac{1}{8} & \frac{1}{8} & 5 \\ 3 & 5 & 1 & 1 & 2 & \frac{1}{8} & \frac{1}{8} & 1 \\ \frac{1}{8} & \frac{1}{6} & \frac{1}{4} & \frac{1}{2} & 1 & \frac{1}{8} & \frac{1}{8} & \frac{1}{7} \\ 8 & 8 & 8 & 8 & 8 & 1 & 8 & 8 \\ 5 & 8 & 8 & 8 & 8 & \frac{1}{8} & 1 & 1 \\ 2 & \frac{1}{5} & \frac{1}{8} & 1 & 7 & \frac{1}{8} & 1 & 1 \end{pmatrix} \end{array}$$

$$\text{A}_{normalized} = \begin{array}{c} \\ Costs \\ Potential \\ Lead-time \\ Fulfilment \\ Exchange \\ Political \\ DG \\ Criticality \end{array} \begin{array}{c} \begin{array}{cccccccc} Costs & Potential & Lead-time & Fulfilment & Exchange & Political & DG & Criticality \end{array} \\ \begin{pmatrix} 0.041 & 0.009 & 0.051 & 0.017 & 0.182 & 0.067 & 0.019 & 0.0229 \\ 0.166 & 0.036 & 0.01 & 0.01 & 0.136 & 0.067 & 0.012 & 0.231 \\ 0.041 & 0.181 & 0.051 & 0.05 & 0.091 & 0.067 & 0.012 & 0.231 \\ 0.124 & 0.181 & 0.051 & 0.05 & 0.044 & 0.067 & 0.012 & 0.046 \\ 0.005 & 0.006 & 0.013 & 0.025 & 0.022 & 0.067 & 0.012 & 0.007 \\ 0.332 & 0.289 & 0.406 & 0.399 & 0.1819 & 0.533 & 0.748 & 0.37 \\ 0.206 & 0.029 & 0.406 & 0.399 & 0.182 & 0.067 & 0.092 & 0.046 \\ 0.083 & 0.007 & 0.01 & 0.05 & 0.159 & 0.067 & 0.093 & 0.045 \end{pmatrix} \end{array}$$

Step 2 To find an approximation to w_{max} (to be used as our estimate of w), we estimate w_i as the average of the entries in row i of A_{norm}. This yields for $w_1 = \frac{.041+.009+.051+.017+.182+.067+.019+.023}{8} = .051$ for objective 1 (costs), $w_2 = .083$ for objective 2 (potential), $w_3 = .090$ for objective 3 (Lead-time), $w_4 = .072$ for objective 4 (fulfilment), $w_5 = .019$ for objective 5 (exchange rates), $w_6 = .407$ for objective 6 (Fufilment), $w_7 = .211$ for objective 7 (dangerous goods) and $w_8 = .064$ for objective 8 (criticality parts).

Averaging these numbers should give a good estimate of the percentage of total weight that should be given to the multiple objectives [Winston, 1994].

Checking for consistency
We can now use the following four-step procedure to check for the consistency of the decision maker's comparison.

Step 1 Compute Aw^T. For our example we obtain:

$$Aw^T = \begin{bmatrix} 1 & \frac{1}{4} & 1 & \frac{1}{3} & 8 & \frac{1}{8} & \frac{1}{5} & \frac{1}{2} \\ 4 & 1 & \frac{1}{5} & \frac{1}{5} & 6 & \frac{1}{8} & \frac{1}{8} & 5 \\ 1 & 5 & 1 & 1 & 4 & \frac{1}{8} & \frac{1}{8} & 5 \\ 3 & 5 & 1 & 1 & 2 & \frac{1}{8} & \frac{1}{8} & 1 \\ \frac{1}{8} & \frac{1}{6} & \frac{1}{4} & \frac{1}{2} & 1 & \frac{1}{8} & \frac{1}{8} & \frac{1}{7} \\ 8 & 8 & 8 & 8 & 8 & 1 & 8 & 8 \\ 5 & 8 & 8 & 8 & 8 & \frac{1}{8} & 1 & 1 \\ 2 & \frac{1}{5} & \frac{1}{8} & 1 & 7 & \frac{1}{8} & 1 & 1 \end{bmatrix} \begin{bmatrix} 0.051 \\ 0.083 \\ 0.090 \\ 0.072 \\ 0.019 \\ 0.407 \\ 0.211 \\ 0.064 \end{bmatrix} = \begin{bmatrix} 0.468 \\ 0.837 \\ 1.108 \\ 0.914 \\ 0.185 \\ 5.147 \\ 2.706 \\ 0.672 \end{bmatrix}$$

Step 2 Compute consistency index (CI) as follows:

$$\frac{1}{8}\left[\frac{0.468}{0.051}+\frac{0.837}{0.083}+\frac{1.108}{0.090}+\frac{0.914}{0.072}+\frac{0.185}{0.019}+\frac{5.147}{0.407}+\frac{2.706}{0.211}+\frac{0.672}{0.064}\right]=11.185 \quad (14)$$

$\text{CI} = \frac{11.185-n}{n-1} = \frac{11.185-8}{7} = 0.455$

Step 3 Compare CI to the random index (RI) for the appropriate value of n, If $\frac{CI}{RI} \leq .10$, the degree of consistency is satisfactory [Winston, 1994].

In our AHP the $\frac{CI}{RI}$ ratio is 0.31. This is a result of matrix sizes and numbering criteria with high number like for e.g. an 8. After all, in our model, weights between certain criteria just make a big difference for the decision maker. We will discuss this within our model validation in the following chapter.

Within Vanderlande we noticed divergent views on utility of this new warehouse in weighting objectives.

Measures of these given objectives are provided throughout this entire study, from costs perspectives this is quite straightforward. We use yearly cumulative costs for each alternative location, warehouse function and flow allocation as input for our AHP model. Potential sales of alternative countries are provided in Section 4.5, for each location and industry we use the replenishment sales forecast of 2022.

As provided in Section 4.7, most benefits objectives are provided by country. For example we know frequency of Order-lines to different countries in the Asia-Pacific region. We define Customer order Lead-time for alternative locations, warehouse functions and decisions on which flow to allocate to the new warehouse.

Country	**HK**	**SG**	**TW**	**AU**	**JP**	**NL**	**TH**	**IN**	**CN**	**ID**	**PH**	**VN**	**KH**	**BN**	**MM**
Political risk index number	92	91	89	85	85	84	76	70	69	69	68	68	67	64	63
Criticality order-lines to Asia-Pacific	43	7	0	339	0	0	4	2	21	8	0	5	9	1	0
DG items flow to Asia-Pacific	0	0	0	46	0	0	0	5	21	0	0	0	4	0	0
Order-lines from Stocked items	16	6	0	626	0	0	3	1	22	15	0	7	5	1	9
StDev Exchange rate indices	8.76	8.96		10.19	9.35	4.25	11.74	19.66	14.38	111.64	26.02				
Exchange rate prioritization	9	8		6	7	10	5	3	4	1	2				
Obtainable Lead-time reduction *	2	2	2	10	2	0	2	2	6	2	2	2	2	2	2

Table 19: Input AHP model

In Table 20 and Table 21 below we provide an illustration on how we evaluate the relative preference of each alternative. All elements of alternatives are provided in the first 4 columns.

LOCATION	FUNCTION	FLOW ALTERNATIVE	MARKET	COSTS	RANK	POTENTIAL FY22	LEAD-TIME	FULFILMENT	EXCHANGE	POLITICAL	DG	CRITICALITY
Melbourne	Stock-location	APAC flow	WP&P, AU	€26.078	7	€2.135.023	10	626	6	85	46	339
Melbourne	Stock-location	APAC flow + direct flow APAC	WP&P, AU	€26.975	7	2135023	10	626	6	85	46	339
Melbourne	Stock-location	APAC flow + direct + APAC supply	WP&P, AU	€52.336	4	€2.135.023	5	626	6	85	46	339
Melbourne	Distribution center	APAC flow	WP&P, AU	€66.607	3	€2.135.023	20	626	6	85	46	339
Melbourne	Distribution center	APAC flow + direct flow APAC	WP&P, AU	€74.501	2	€2.135.023	20	626	6	85	46	339
Melbourne	Distribution center	APAC flow + direct + APAC supply	WP&P, AU	€102.880	1	€2.135.023	15	626	6	85	46	339
Shanghai	Stock-location	APAC flow	AIRPORT, CN	€25.267	7	€969.862	6	22	4	69	21	21
Shanghai	Stock-location	APAC flow + direct flow APAC	AIRPORT, CN	€25.999	7	€969.862	6	22	4	69	21	21
Shanghai	Stock-location	APAC flow + direct + APAC supply	AIRPORT, CN	€41.859	5	€969.862	1	22	4	69	21	21
Shanghai	Distribution center	APAC flow	AIRPORT, CN	€54.475	4	€969.862	16	22	4	69	21	21
Shanghai	Distribution center	APAC flow + direct flow APAC	AIRPORT, CN	€58.019	4	€969.862	16	22	4	69	21	21
Shanghai	Distribution center	APAC flow + direct + APAC supply	AIRPORT, CN	€77.418	2	€969.862	11	22	4	69	21	21
…	…	…	..	…	…	…	…	…	…	…	…	…
SUM					4228	477721488	7720	58572	3612	64776	16308	37284

Table 20: Input AHP model for 786? alternatives example set of locations

Each element of the above given alternative is evaluated on relative weighted percentage by the cumulative value of all 786 alternatives. The solution can be found by finding the alternative with the highest weighted (w_i) relative percentage of all elements.

LOCATION	FUNCTION	FLOW ALTERNATIVE	MARKET	COST	POTENTIAL FY22	LEAD-TIME	FULFILMENT	EXCHANGE	POLITICAL	DG	CRITICALITY
Melbourne	Stock-location	APAC flow	WP&P, AU	$\frac{7}{4228} * w_i$	$\frac{2135023}{477721488} * w_i$	$\frac{10}{7720} * w_i$	$\frac{626}{58572} * w_i$	$\frac{6}{3612} * w_i$	$\frac{85}{64776} * w_i$	$\frac{46}{16308} * w_i$	$\frac{339}{37284} * w_i$
Melbourne	Stock-location	APAC flow + direct flow APAC	WP&P, AU	$\frac{7}{4228} * w_i$	$\frac{2135023}{477721488} * w_i$	$\frac{10}{7720} * w_i$	$\frac{626}{58572} * w_i$	$\frac{6}{3612} * w_i$	$\frac{85}{64776} * w_i$	$\frac{46}{16308} * w_i$	$\frac{339}{37284} * w_i$
Melbourne	Stock-location	APAC flow + direct + APAC supply	WP&P, AU	$\frac{4}{4228} * w_i$	$\frac{2135023}{477721488} * w_i$	$\frac{5}{7720} * w_i$	$\frac{626}{58572} * w_i$	$\frac{6}{3612} * w_i$	$\frac{85}{64776} * w_i$	$\frac{46}{16308} * w_i$	$\frac{339}{37284} * w_i$
Melbourne	Distribution center	APAC flow	WP&P, AU	$\frac{3}{4228} * w_i$	$\frac{2135023}{477721488} * w_i$	$\frac{20}{7720} * w_i$	$\frac{626}{58572} * w_i$	$\frac{6}{3612} * w_i$	$\frac{85}{64776} * w_i$	$\frac{46}{16308} * w_i$	$\frac{339}{37284} * w_i$
Melbourne	Distribution center	APAC flow + direct flow APAC	WP&P, AU	$\frac{2}{4228} * w_i$	$\frac{2135023}{477721488} * w_i$	$\frac{20}{7720} * w_i$	$\frac{626}{58572} * w_i$	$\frac{6}{3612} * w_i$	$\frac{85}{64776} * w_i$	$\frac{46}{16308} * w_i$	$\frac{339}{37284} * w_i$
Melbourne	Distribution center	APAC flow + direct + APAC supply	WP&P, AU	$\frac{1}{4228} * w_i$	$\frac{2135023}{477721488} * w_i$	$\frac{15}{7720} * w_i$	$\frac{626}{58572} * w_i$	$\frac{6}{3612} * w_i$	$\frac{85}{64776} * w_i$	$\frac{46}{16308} * w_i$	$\frac{339}{37284} * w_i$
Shanghai	Stock-location	APAC flow	AIRPORT, CN	$\frac{7}{4228} * w_i$	$\frac{969862}{477721488} * w_i$	$\frac{6}{7720} * w_i$	$\frac{22}{58572} * w_i$	$\frac{4}{3612} * w_i$	$\frac{69}{64776} * w_i$	$\frac{21}{16308} * w_i$	$\frac{21}{37284}$
Shanghai	Stock-location	APAC flow + direct flow APAC	AIRPORT, CN	$\frac{7}{4228} * w_i$	$\frac{969862}{477721488} * w_i$	$\frac{6}{7720} * w_i$	$\frac{22}{58572} * w_i$	$\frac{4}{3612} * w_i$	$\frac{69}{64776} * w_i$	$\frac{21}{16308} * w_i$	$\frac{21}{37284} * w_i$
Shanghai	Stock-location	APAC flow + direct + APAC supply	AIRPORT, CN	$\frac{5}{4228} * w_i$	$\frac{969862}{477721488} * w_i$	$\frac{1}{7720} * w_i$	$\frac{22}{58572} * w_i$	$\frac{4}{3612} * w_i$	$\frac{69}{64776} * w_i$	$\frac{21}{16308} * w_i$	$\frac{21}{37284} * w_i$
Shanghai	Distribution center	APAC flow	AIRPORT, CN	$\frac{4}{4228} * w_i$	$\frac{969862}{477721488} * w_i$	$\frac{16}{7720} * w_i$	$\frac{22}{58572} * w_i$	$\frac{4}{3612} * w_i$	$\frac{69}{64776} * w_i$	$\frac{21}{16308} * w_i$	$\frac{21}{37284} * w_i$
Shanghai	Distribution center	APAC flow + direct flow APAC	AIRPORT, CN	$\frac{4}{4228} * w_i$	$\frac{969862}{477721488} * w_i$	$\frac{16}{7720} * w_i$	$\frac{22}{58572} * w_i$	$\frac{4}{3612} * w_i$	$\frac{69}{64776} * w_i$	$\frac{21}{16308} * w_i$	$\frac{21}{37284} * w_i$
Shanghai	Distribution center	APAC flow + direct + APAC supply	AIRPORT, CN	$\frac{2}{4228} * w_i$	$\frac{969862}{477721488} * w_i$	$\frac{11}{7720} * w_i$	$\frac{22}{58572} * w_i$	$\frac{4}{3612} * w_i$	$\frac{69}{64776} * w_i$	$\frac{21}{16308} * w_i$	$\frac{21}{37284} * w_i$

Table 21: Output AHP; find optimum between relative costs, potential and benefits

4.8.2 Results of AHP

In Figure 17 below we illustrate the relative weighted percentages from different alternatives by our AHP model. Optimal solutions will come forward on highest scores between the sum of weighted relative objectives, as explained previously. To illustrate alternatives from our AHP we provide two examples.

Based on results of our AHP, taking into account all criteria, we conclude that the optimum scenario is opening a Distribution center in Melbourne to serve APAC demand. This warehouse will essentially serve Australian WP&P customer sites.

By continuously providing (sub)conclusions in our study, this happily does not come as a miracle. In almost all designations on different service perspectives, we usually concluded that the new warehouse facility should be located in or near Melbourne. The achievable benefits will compensate facility costs.

We noticed divergent views on utility of this new warehouse in weighting objectives for our AHP.

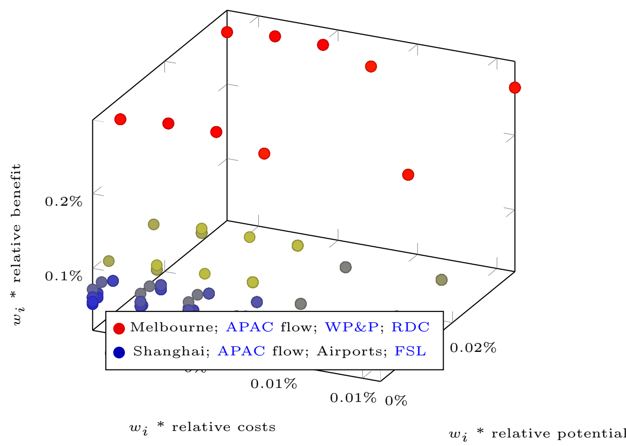

Figure 17: AHP weighted relative percentages

After studying results of following similar AHP procedures with weights from other managers within Vanderlande, we conclude that optimal scenario's will not change by giving various weights to our objectives.

4.9 Conclusions

On the basis of of separating alternative decisions for allocating relevant flows, we are able to see that savings on transportation costs are results from delivering goods to Asia-Pacific customer sites *and not* by delivering goods for EMEA and AMER demand from this new regional warehouse facility.

Locating the new regional warehouse in for example China will reduce warehousing costs, mainly because of low throughput rates and storage costs in certain countries. Import costs are minimal when Vanderlande would locate the regional warehouse in Australia, *because in Australia for most import value Vanderlande Vanderlande Spare Parts only has to pay import duties once.*

The total value of inventory hold on stock for the demand from Asia-Pacific customer sites is minimal (€ 53.726). Based on conclusions in our inventory allocation model about order fulfilment, we stated that Vanderlande should locate the regional warehouse in Melbourne. As outcome of research we noticed that around 80% of Order-lines fulfilled from stock will go to Australian (WP&P) customer sites in future.

In resolution to 11th RQ: *"How could we improve optimal sourcing for customer sites for different alternatives considering growth path in the Asia-Pacific region?"*, based on timely delivery of Dangerous goods and Criticality parts, Vanderlande should open a regional warehouse. In general Customer order Lead-time towards Asia-Pacific customers is demonstrated to be shortest from a warehouse in Australia.

Based on our AHP, we conclude that the optimal scenario is opening a Distribution center in Melbourne. Opening a warehouse in Melbourne to serve all Asia-Pacific demand will cost € 11.577 per year.

Due to alternately high import costs or transportation and warehousing costs *we make future prognosis of only increasing costs over the next 5 years for the relevant warehouse locations.* Appearing costs are not significant compared to the beneficial factors that will occur with opening this warehouse facility.

The strongest growth among all different countries and industries is growth from Australian WP&P customers. This gives motivation that *based on future sales it is beneficial to locate in Australia.*

All Australian WP&P customer sites this sentence is removed for publication are located in Melbourne. We therefore advise to place the regional warehouse close to these Australian WP&P customers sites.

5 Model validation and sensitivity analysis

In this chapter we provide different methods model validation we used, furthermore we provide Vanderlande the opportunity to perform sensitivity analysis on model input parameters.

5.1 Model validation

Methods of data preparation
In this study we refined data sources so it can be used effectively for solving the initial stated problem statement. In appendix A6 we provide the methods of data preparation.

Costs estimations
In order to validate our *transportation costs* distribution we determine outbound freight, invoiced between january 2017 and may 2018, from the central warehouse to the customer sites.

In the table below we compare above mentioned invoiced freight with our costs distribution, by assuming transportation costs for certain distances from the central warehouse to customer sites. In the table we give approximation of the transportation costs for ***both Replenishment parts and Packages***.

This table is removed for publication.

Assuming that for inbound logistics the rate of €1.04 counts for all different country regions (because most parts are sourced in EMEA), we get close to the actual invoiced costs. In general Vanderlande Spare Parts invoices higher transportation costs to customers than actually consumed.

Inventory costs are validated by repeatedly going through formula's in our spreadsheets. We validated *warehouse and import costs* by taking alternatives input parameters and undertake manual calculations.

Consistency of MCDA
The consistency index of our AHP model is 0.31, this is above the 0.1 degree of consistency that is considered satisfactory in terms of yielding meaningful results [Winston, 1994]. The paper "Consistency Prediction for Incomplete AHP Matrices" of [WEDLEY, 1993] developed a methodology for predicting the consistency index and consistency ratio when pairwise comparisons are incomplete. Conclusions where that matrix size make difference in the model acceptance, the more consistency ratio values the more >0.1 is acceptable.

Model validation by client acceptance
Another important method of model validation is by communication with our supervisors at Vanderlande. Frequently we validated our model by questioning whether our model "fits" within real perception. Warehousing storage and throughput rates, as provided in Section 2.3, might be higher in practice.

5.2 Sensitivity analysis

In our research we made strong assumptions for estimating both warehousing and import costs. First of all we assume certain storage costs and throughput rates based on property indexes and GDP per capita. When Vanderlande would verify public warehousing rates and import tariffs in the Asia-Pacific region, there is a possibility of coming to different input parameters than used in our model.

In our study we assumed that import tax rates from the regional warehouse to customer sites are 5% for all different countries. We provide the opportunity to perform sensitivity analysis on facility location import tariffs and final import tariffs by using the one-at-a-time approach, as given in our literature review.

In the table below we provide two alternative sensitivities on final import tariffs (1% or 10%), besides in same alternative sensitivities we use two different percentages on the warehousing storage and throughput rates (200% or 80% of the rates held in our main model).

IMPORT COSTS	**Sensitivity**	**AU**	**BN**	**CN**	**HK**	**ID**	**IN**	**KH**	**MM**	**PH**	**SG**	**TH**	**TM**	**TW**	**VN**	**NL**
Location import tariffs	Applied	2%	0%	4%	0%	7.5%	5%	0%	5%	1%	0%	3%	2%	5%	0%	0%
	Sensitivity 1&2	2%	0%	4%	0%	7.5%	5%	0%	5%	1%	0%	3%	2%	5%	0%	0%
Final import tariffs	Applied	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
	Sensitivity 1	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
	Sensitivity 2	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
WAREHOUSING COSTS	**Storage rates**			**Throughput rates**												
Sensitivity	Applied	Sensitivity 1	Sensitivity 2	Applied	Sensitivity 1	Sensitivity 2										
Percentage of costs	100%	200%	80%	100%	200%	80%										

Table 22: Sensitivity on final import tariffs and warehousing storage and throughput rates

Each of the above given (facility location or final) import tariffs can be adjusted in our supplied model by meaning of the one-at-a-time approach from literature. Furthermore we provide the opportunity to perform sensitivity analysis on each separate warehouse location's storage and throughput rates.

In the figure below we illustrate the two sensitivities as described above. This is just an example. By using one-at-a-time approach the management of Vanderlande is able to apply many different sensitivities.

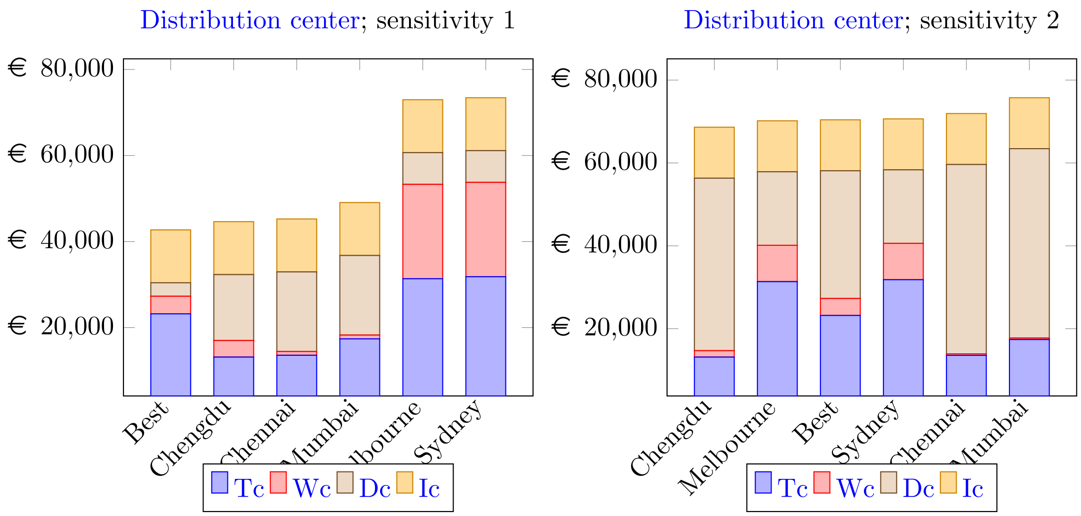

Figure 18: Sensitivity on yearly costs for serving APAC demand by alternative RW location index-year 2017

From this illustration we notice that applying different rates for import tariffs or warehousing costs can change perspectives on costs significantly. We therefore strongly recommend to find exact import tariffs from Australia to all countries of final customer site delivery and implement this in our spreadsheets.

6 Implementation plan

This chapter contains the implementation plan for the network redesign of the Asia-Pacific region.

6.1 Goals and strategy

The first step in the implementation of this new service network redesign is defining strategy directions on how to make this implementation feasible.

Problem statement

Vanderlande is currently facing a strong growth, amongst others in the Asia-Pacific region. The mission of Vanderlande is to improve the competitiveness of its customers through value-added logistic process automation. By controlling the supply of spare parts in Asia-Pacific region via the central warehouse in Best, the question arises if Vanderlande succeeds in this mission in this region.

Throughout our study we clearly demonstrated that opening a Asia-Pacific warehouse facility will provide multiple benefits to Vanderlande's customer sites. Costs will not be the critical factor for deciding whether and where to open a regional warehouse facility.

Goal statement

To improve availability of spare parts for Vanderlande's customer sites in the Asia-Pacific region by setting up a new regional warehouse facility in Melbourne, Australia. This while setting up this new facility against minimum costs, while considering sensitivity in our optimization model and lastly by taking into account availability of required infrastructure in determining the best possible location.

Strategy description

We first identify a subset of customer sites that will be affected by this strategy. This subset includes all customer sites provided in appendix A4. But especially WP&P customer sites will acquire benefits from this change, we should inform these WP&P customer sites about Vanderlande's willingness of improving availability of spare parts for their WP&P installations.

But before even setting up this warehouse, we recommend Vanderlande to perform sensitivity analysis on assumptions we made throughout this study. To finalize warehouse location decisions Vanderlande Spare Parts has to gain information about:

- Exact warehousing storage and throughput costs in Melbourne, Australia.
- Exact import tarrifs from Australia to countries of final customer site delivery.

Findings can be implemented through sensitivity analysis in our model, supplied in the attached "AHP Network Optimization Model" Excel file. The results will form precise facility costs estimations.

To implement this strategy, we first have to find a public warehouse that will facility our activities in the Asia-Pacific region. There are several companies like DHL, FedEx and Visa Global Logistics that offer public warehouse services. We advise to request all companies for a tender and compare warehousing rates and offered services. Outcomes should be implemented in our model.

As result from our inventory model, we are able to provide quantities of items that should be kept on stock in the regional warehouse.

Since we are only interested in serving APAC demand from this new facility, we only refer to appendix B6 and B8 for our inventory advises. All proposed items to keep on stock are currently available in the central warehouse. In order to save initial ordering costs, Vanderlande could decide to replenish the first items from the central warehouse.

After finding an optimum location within Melbourne and transferring stock to the new warehouse facility it is essential to measure spare part supply performance for Vanderlande's Asia-Pacific customer sites. We will provide important performance measures later in this chapter.

6.2 Approach

In order to have a successful implementation of this new service network redesign, we need to define important barriers and responsibilities. Simultaneously, this forms the leading milestones of the implementation.

Step	**Implementation Steps**	
Nr	**Activity (e.g., data collection, finding locations, purchases)**	**Who is responsible?**
1	Perform sensitivity analysis on optimization model	Stefan en Thijs
2	Find optimal public warehouse in Melbourne taking into account infrastructure requirements	Stefan van Venrooij
3	Make decisions on which inventory to hold and how to replenish first items	Stefan van Venrooij
4	Inform Asia-Pacific WP&P customer sites about new warehouse	Frank van Schijndel
5	Built performance measurement system and measure performance of new facility	Maarten Schaaf

Table 23: Barriers to successful implementation

Vanderlande Spare Parts should inform relevant stakeholders within this change. The regional warehouse will for example essentially serve WP&P customer sites, this could form discussion on cost allocation between different Customer centers. Besides it is important to inform relevant Customer centers and spare parts coordinators who are active within this region. In Table 24 below we provide the communication strategy.

Communications Strategy	
Who needs to know about the strategy?	**What information do they need?**
Department Logistical Support	Strategy direction and education plan to sent APAC demand over new warehouse facility
Airports and WP&P directors	Research results on which industry this new warehouse facility will essentially serve
Customer centers in APAC region	Strategy direction and education plan to sent APAC demand over new warehouse facility
APAC customer sites	Strategy of opening new warehouse to serve customer sites timely with spare parts

Table 24: Communication strategy

6.3 Performance measures

The most critical factor after implementation is measuring performance of the new regional warehouse facility. If Vanderlande will not pay attention on factors like Customer order Lead-time, there is a high risk that customer sites will not acquire any benefits from this new network strategy.

Nr	**Performance measures**	**KPI's**
1	Average Customer order Lead-time for Replenishment parts	Lead-time in days
2	Average Customer order Lead-time for Packages	Lead-time in days
3	On time delivery Promised Ship Date for Replenishment parts	Percentage on time APAC replenishment orders
4	On time delivery Promised Ship Date for Packages	Percentage on time APAC packages orders
5	Actual Shipped Order-lines for Replenishment parts	Number of Order-lines
6	Actual Shipped Order-lines for Packages	Number of Order-lines.
7	Specified Fraction of demand satisfied from inventory [Silver et al., 2016]	Fill rate (or $P2$) of APAC demand
8	Supplier Lead-time of spare parts to new warehouse facility	Lead-time in days

Table 25: Performance measures

Although this is just a minor representation of all steps to take for setting up a new warehouse, we think this should form an alignment to a successful implementation.

7 Conclusions, recommendations and limitations

In this chapter we will provide conclusions in response to our problem statement. Based on the results of our solution approaches, we provide recommendations towards the global spare parts department.

7.1 Conclusions

In the conclusions all elements of this study will come together. Here we answer our main research questions and verify whether we achieved the research objective.

Response to main research question
Given our problem statement, the main question of this research is: *"Does it make sense to open a warehouse to serve the Asia-Pacific region. And if it makes sense, where should this warehouse be located (China or somewhere else in the region)? And if it would appear to be to early too open a warehouse in that region: what is the break-even point in spare part volume for which such a warehouse would be profitable?"*

Based on abilities of timely delivery Dangerous goods and Criticality parts to Vanderlande's Asia-Pacific customer sites, it makes sense to open a regional warehouse. In general Customer order Lead-time towards Asia-Pacific customers is demonstrated to be shortest from a regional warehouse in Australia.

The mission of Vanderlande is to improve the competitiveness of its customers through value-added logistic process automation. By controlling the supply of spare parts in Asia-Pacific region via a warehouse facility in the Asia-Pacific region, Vanderlande will execute it's mission statement for customer sites within this region. Customer order Lead-time of replenishment parts is a critical factor for the customers system uptime.

Based on conclusions of our model about order fulfilment, we should locate our regional warehouse in Melbourne. More than 80% Order-lines from Stocked items will be delivered to Australian WP&P customers. Furthermore most critical and dangerous items that should be kept on stock from our inventory advise, are intended for Australian WP&P market. When Vanderlande would open a this warehouse facility, Vanderlande has to count for around €53.726 of *inventory value* on stock for serving Asia-Pacific demand.

From results of our AHP, we conclude that the optimum alternative is opening a Distribution center in Melbourne to serve all Asia-Pacific replenishment demand. Next to fulfilling orders from Stocked items, this warehouse should function as Cross docking location for all Asia-Pacific demand. To begin, Vanderlande Spare Parts should fulfil all Australian WP&P orders from this regional warehouse facility.

Opening a Distribution center in Melbourne to serve Asia-Pacific customer sites will approximately cost €11.577 per year. If Vanderlande prefers to keep all critical and dangerous items on stock, one could expect higher (future) inventory and warehousing costs. Furthermore, when Vanderlande would source in the same country as the country location of the regional warehouse, cost reduction might become realistic.

Taking into account growth path we expect only increasing future operating costs for this new facility. However, additional supply chain costs will not become significant (€17.419 in 2022).

From the study, we conclude that costs will not be the most critical factor for deciding whether and where to open a regional warehouse to serve Asia-Pacific demand. The extra yearly costs are not significant.

Resolution to research objective
After answering the main research questions throughout this study, it can be concluded that the initial stated research objective is achieved.

First of all we were able to estimate (future) costs for setting up a warehouse facility to serve the Asia-Pacific region. We therefore built an optimization model. Decisions on warehouse locations are based on an interaction between various criteria, we were able to make our decisions by solving a MCDA problem.

Assuming linear growth we were able to prove that opening a regional warehouse at a relevant location will not be profitable now nor in longer future. However we evaluated that Vanderlande can count on shorter Customer order Lead-time by opening this new regional Asia-Pacific warehouse facility.

7.2 Recommendations

Various findings have been discovered during the execution of this study. Based on these findings we will give key recommendations towards the management of the global spare parts department.

- Since establishment climate of western countries will give benefits on import costs and emerging economies will result in low warehousing costs, perspectives on (future) costs support that our location decision should come forward on beneficial factors like e.g. customer's systems uptime only.
- Vanderlande Spare Parts should develop an explicit competitive strategy. It is difficult or maybe even impossible to make network distribution decisions without setting strategic supply chain objectives from for example trade-offs between service levels and costs. This explains divergent views from managers on utility of this new regional facility in weighting benefits and costs for our AHP model.
- However, setting up the regional warehouse will increase Vanderlande its ability to provide customer sites timely with spare parts. Therefore Vanderlande will improve its competencies to help Asia-Pacific customers sites increasing their uptime. This could lead to more project sales in this region. Besides, Vanderlande will be able to offer certain products like maintenance contracts in this region.
- Almost all Order-lines fulfilled from Stocked items will be delivered to Australian WP&P customer sites. Besides most critical and dangerous items that Vanderlande should keep on stock by our inventory advise, are intended for Australian WP&P market. Based on shortest Customer order Lead-time and customer's systems uptime, we therefore advise to set up the regional warehouse in Melbourne.
- To begin, Vanderlande should start fulfilling all Australian WP&P orders from the new warehouse in Melbourne. After appropriate implementation, we advise to serve all APAC demand from this facility.
- Furthermore, not even taking into account current Packages sales, we noticed strongest growth among Australian WP&P customer sites.
- Vanderlande should change its sourcing strategy simultaneously with the redesign of the service network. Benefits can be achieved if Vanderlande sources in the same country as the new facility location.

7.3 Limitations

Below we present all limitations of this research. These restrictions could influence conclusions reached throughout this study.

- Using only single echelon models for determining differences between warehouse locations, results in conclusions that might not be the exact real world situation. The current regional warehouse in Acworth often replenish via the central warehouse in Best.
- As stated in the research scope, replenishment sales can develop in future Packages sales. We only used replenishment sales in our modelling.
- Our estimated warehousing costs can differ from reality. It was difficult to get exact estimations without requesting offers from companies like DHL for alternative countries. It is even questionable whether a company like DHL will cooperate in outsourcing the required six cubic metre Asia-Pacific warehouse.
- Due to unavailability of information of import duties for sending goods from the regional warehouse to final country destinations, we assumed that Vanderlande would pay 5% on import duties.
- Inventory costs in Best should probably be lower. Because all items to be kept on stock in the proposed new regional warehouse are currently available in central warehouse in large numbers, Vanderlande will profit from centralized stock what results in lower inventory costs.

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A Appendices

A.1 Network design framework and research framework

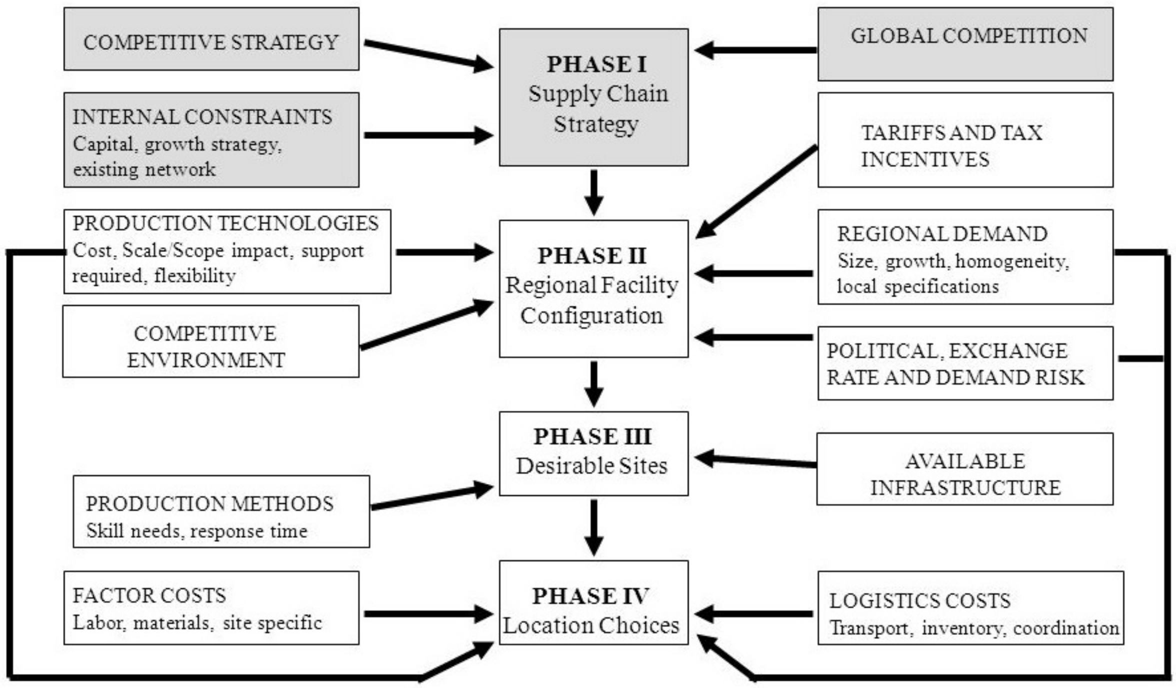

Figure 19: Framework network design decisions of Chopra and Meindl

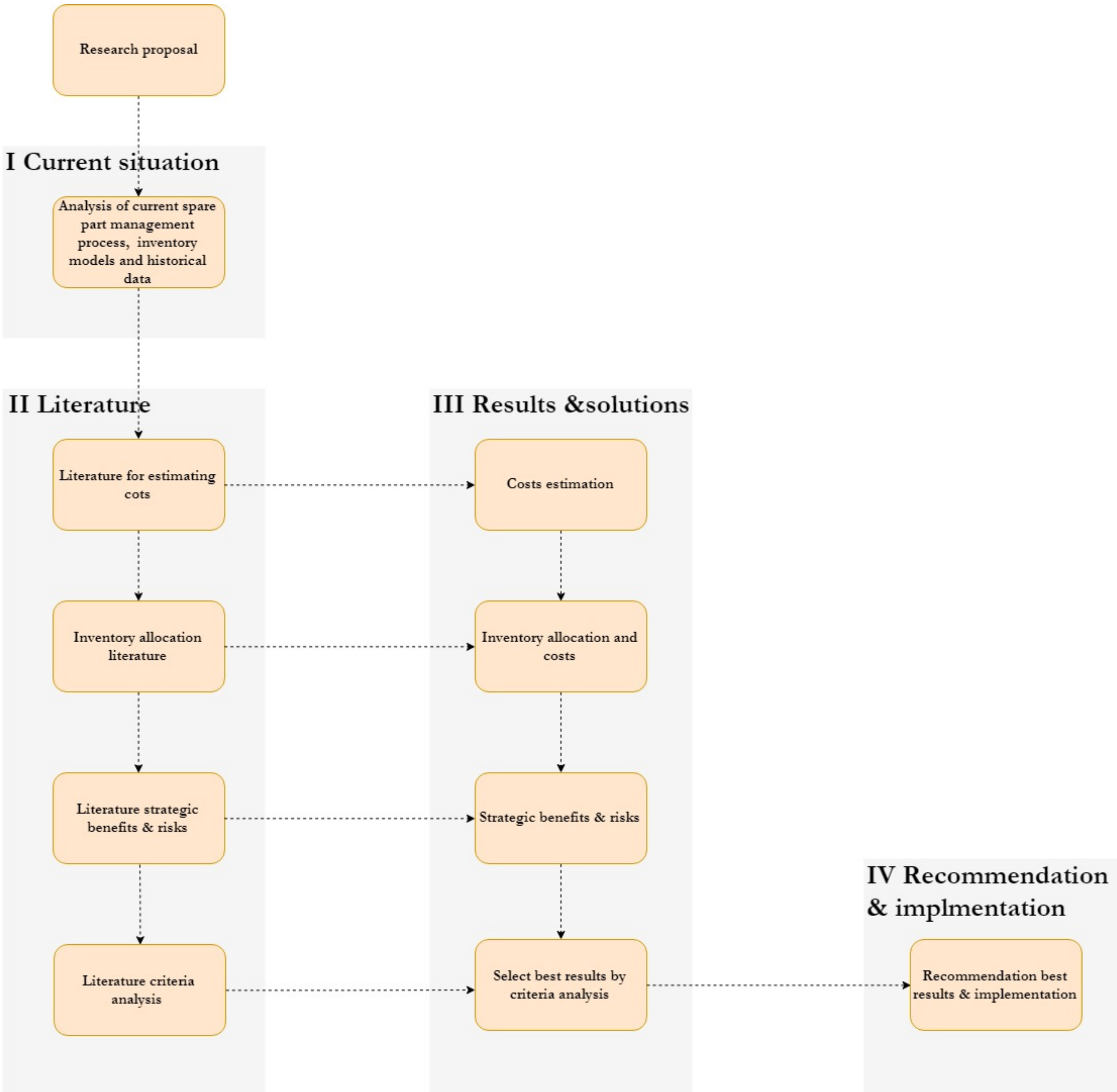

Figure 20: Research framework

A.2 Current flow specification

FlowNum	Arrow	Color	Decomposed flow	Inbound/Outbound	Direct or via central warehouse
1	→	Green	APAC supplier to central warehouse	Inbound	Central warehouse in Best
2	→	Gray	AMER supplier to central warehouse	Inbound	Central warehouse in Best
3	→	Yellow	EMEA supplier to central warehouse	Inbound	Central warehouse in Best
4	→	Purple	Central warehouse to APAC customer	Outbound	Central warehouse in Best
5	→	Blue	Central warehouse to AMER customer	Outbound	Central warehouse in Best
6	→	Red	Central warehouse to EMEA customer	Outbound	Central warehouse in Best
7	→	Pink	APAC supplier to APAC customer	Inbound/Outbound	Direct delivery from suppliers
8			EMEA supplier to APAC customer	Inbound/Outbound	Direct delivery from suppliers
9			AMER supplier to APAC customer	Inbound/Outbound	Direct delivery from suppliers

Table 26: Current spares flow

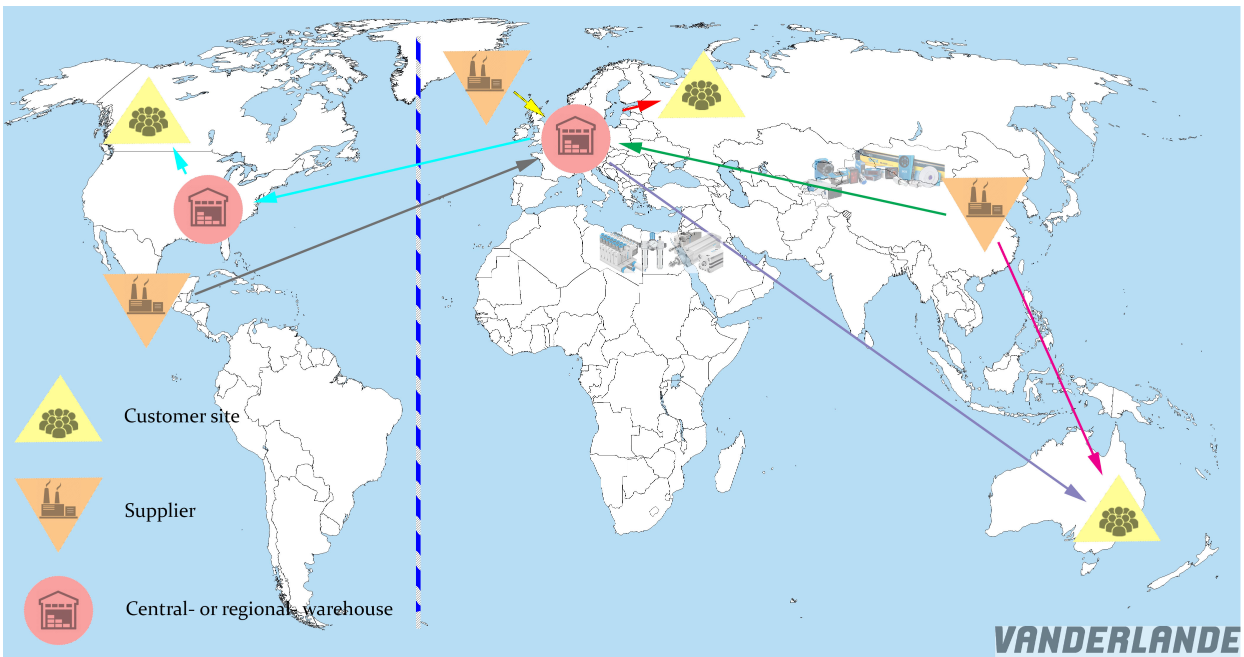

Figure 21: Current global spare part replenishment process

A.3 Proposed flow specification

FlowNum	Arrow	Color	Decomposed flow	Inbound/Outbound	Direct or via regional warehouse
1	→	Green	APAC supplier to regional warehouse	Inbound	Regional Asia-Pacific warehouse
2	→	Gray	AMER supplier to regional warehouse	Inbound	Regional Asia-Pacific warehouse
3	→	Yellow	EMEA supplier to regional warehouse	Inbound	Regional Asia-Pacific warehouse
4	→	Purple	Regional warehouse to APAC customer	Outbound	Regional Asia-Pacific warehouse
5	→	Blue	Regional warehouse to AMER customer	Outbound	Regional Asia-Pacific warehouse
6	→	Red	Regional warehouse to EMEA customer	Outbound	Regional Asia-Pacific warehouse
7	→	Pink	APAC supplier to RW and RW to APAC customer	Inbound/Outbound	Regional Asia-Pacific warehouse
8			EMEA supplier to RW and RW to APAC customer	Inbound/Outbound	Regional Asia-Pacific warehouse
9			AMER supplier to RW and RW to APAC customer	Inbound/Outbound	Regional Asia-Pacific warehouse

Table 27: Proposed spares flow

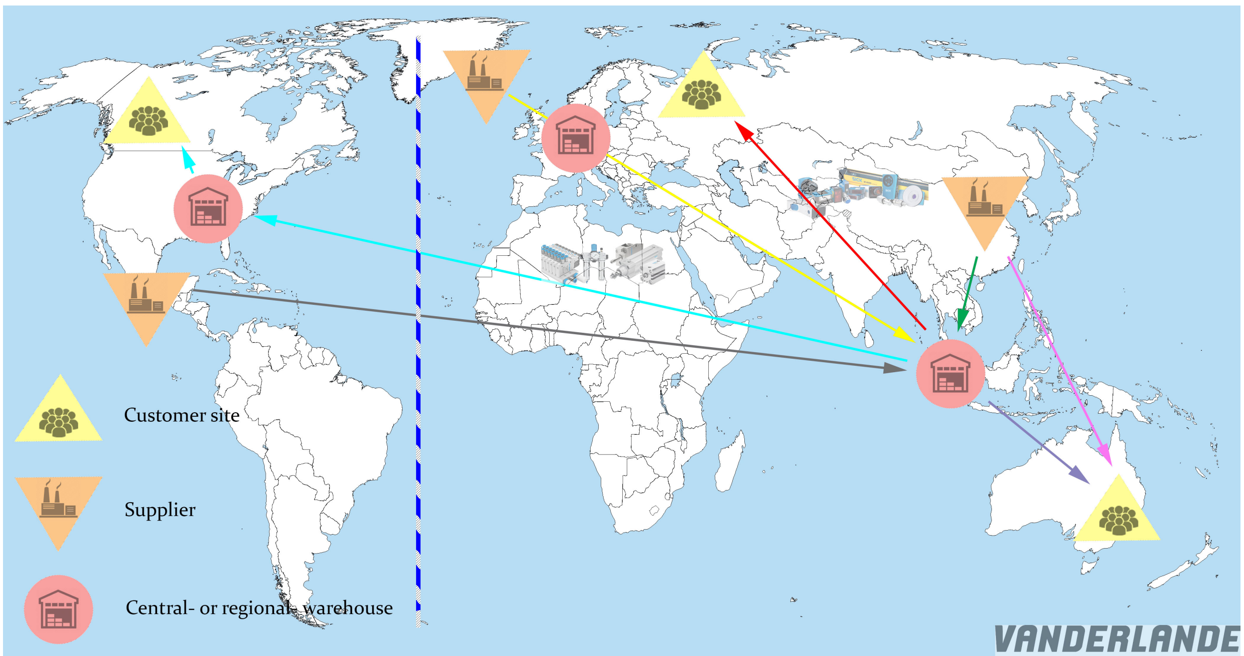

Figure 22: Proposed spare part replenishment flow by regional Asia-Pacific warehouse

A.4 List Asia-Pacific customers and worldwide suppliers

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A.5 Demand-types

Spare Parts Package is a package of spare parts that is composed for a client before new system/ change/ re-built/ renovation/ extension is taken over for use. This is an initial spare parts package purchased by the client as an insurance of the system's up-time. The idea behind it is that there will be enough crucial spare parts stored on-site to repair the system and keep it running. The request for a spare parts package is usually sent to Spare Parts from a project manager or a service manager. The Packages are handled by the commercial team of Sales support. In 2017 the sales of these Packages generated 20% of the total turnover.

Replenishment order is a direct order from a client during the operation time of Vanderlande's system. The replenishment orders are the major part of Spare Parts' turnover. These orders are being placed via the Spare Parts web shop, e-mail or phone. The handling of replenishment orders is a daily routine and is handled by the operational team of Sales Support. In 2017, the sales of spare parts generated nearly 68% of the total turnover [Kupinski, 2018].

A.6 Data components and description on methods of data preparation

- Demand classification, we could benefit from for example allocating especially Fast movers to regional APAC warehouse instead of currently also delivering these parts directly.
- Spare parts sales industries, we could as mentioned above profit from risk pooling with a regional warehouse in APAC when this region has a dominant sales industry like for example airports.
- Order types, replenishments parts or Packages. Important because mainly replenishments parts will be considered as profitable to manage from the regional warehouse.
- Supplier and delivery Customer order Lead-time, we could determine a relationship between time and distances. For example placing a geographically closer RW to customers would reduce Customer order Lead-time and so inventory.
- Adress book, required for decomposing Flow intensities of global demand.
- Distances, for determining relationships between distances and for example transportation costs.
- Country currency's, To gather uniform sales information in euro's.
- Value added tax per country, Because we want to minimize costs due importing goods into a specific geographical country.
- Transportation tracking from DHL, Besides being able to determine relationships between transportation costs, weight and distances.
- Country zones, Using ISO 3166 standards of geo-classifications we are able to acquire all above described spare parts flows by linking supplier and customer countries adresses to these geo-classifications.

First of all we analysed *validity* by checking whether data has the correct data type and matches required patterns. We checked for example like if addresses look like addresses and whether text objects in data could be recognized as spare parts. Secondly we check *completeness* by ensuring all required data sets are available. Moreover where we found *incompleteness* in the data sets like for example in the adressbook or demand classification, external data sources help us to enrich our required datasets. The adressbook is an important component, since it determines the location of the customer site together with its flow intensity for our optimization model. Therefore we verified whether the adresses are *consistent* together with outbound transportation data of DHL. We verified *accuracy* by checking whether the orderdata for GDC-outbound matches with an authoritative data resource (Transfer/Interbranch Sales Information E1-03-06-0005). In addition we found multiple currency's, to get an *uniform* data set we converted this to euro's.

A.7 Procurement direct delivery

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A.8 Table weight direct shipments Asia-Pacific

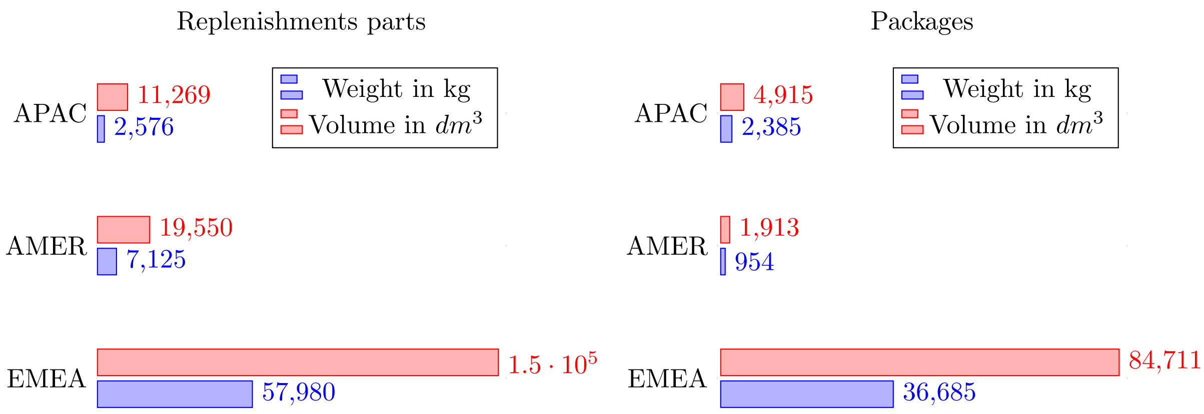

Figure 23: Weight and volume transported direct shipment to country regions 01-01-17 31-05-18

A.9 Table transportation costs distribution

Distance range	0-50km	51-100km	101-200km	201-500km	501-1000km	1001-2000km	2001-5000km	5001-1000km	10001km
Total kg	11.045	24.686	65.855	150.948	307.306	160.350	27.834	134.228	9.918
Average weight	251	287	189	193	191	120	135	156	79
Total cost transported	€ 2.647	€ 8.448	€ 27.416	€ 76.942	€ 192.161	€ 166.444	€ 52.761	€ 192.438	€ 59.600
cij : rate(Euro/kg)	€ 0.24	€ 0.34	€ 0.42	€ 0.51	€ 0.63	€ 1.04	€ 1.90	€ 1.43	€ 6.01

Table 28: WEIGHT DISTRIBUTION AVERAGE COST PER KG DISTANCE RANGES

A.10 Invoice DHL

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A.11 Visa Global Logistics

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A.12 Demand classification central warehouse

Note that Stocked items could be kept on stock in multiple quantities.

Demand classification	Stocked items	Not Stocked items	Total	% of total stocked
Normal	705	71	776	28%
Lumpy	278	79	357	11%
Irregular	680	2.921	3.611	28%
Slow	728	6.976	7.704	29%
Other	96	34.089	34.185	4%
Total	2.497	44.136	46.633	100%

Table 29: Stocked items in central warehouse

A.13 Input parameters EOQ formula

The ordering costs A is an addition of costs of creating a purchase order, costs due invoicing process and costs to be considered for inbound handling of Vanderlande their main carrier DHL.

Costs of creating a purchase order is calculated by dividing the total number of orders by the labour costs of 4 spare part coordinators (46.098 orders / (4* €3.355) = €3.4375/PO). Invoicing costs is estimated at a standard costs of €5 per order.

Moreover, in case of the inbound handling costs of DHL, dividing the hourly rate of €23.35 by receives 7.5orders per hour on average we get to a inbound cost of €3.11 per hour. If we add up these different costs we get to an ordering costs A of €11.55 per purchase order.

Carrying charge r is set on 24% of stock value, to begin because, handling costs, is on average 17% of the total purchase order value. Furthermore Vanderlande carries risk on obsolescence of inventory and besides we have to assign costs from operating the public warehouse.

A.14 Growth path per country Asia-Pacific region

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A.15 Customer sales from order data

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B Appendices

B.1 Set of warehouse locations

Set of locations Best, Netherlands
Abu Dhabi, United Arab Emirates
Adelaide, Australia
Ahmedabad, India
Almaty, Kazakhstan
Ankara, Turkey
Anshan, China
Auckland, New Zealand
Baghdad, Iraq
Bandung, Indonesia
Bangalore, India
Bangkok, Thailand
Baotou, China
Beijing, China
Brisbane, Australia
Bursa, Turkey
Busan, South Korea
Changchun, China
Changsha, China
Changzhou, China
Chengdu, China
Chennai, India
Chittagong, Bangladesh
Chongqing, China
Daegu, South Korea
Daejeon, South Korea
Dalian, China
Daqing, China
Delhi, India
Dhaka, Bangladesh
Doha, Qatar
Dongguan, China
Dongying, China
Dubai, United Arab Emirates
Faisalabad, Pakistan
Foshan, China
Fukuoka–Kitakyushu, Japan
Fuzhou, China
George Town, Malaysia
Guangzhou, China
Gwangju, South Korea
Haifa, Israel
Hamamatsu, Japan
Hangzhou, China
Hanoi, Vietnam
Harbin, China
Hefei, China
Hiroshima, Japan
Ho Chi Minh City, Vietnam
Hong Kong, Hong Kong SAR of China
Hsinchu, Taiwan
Huhehaote, China

Hyderabad, India
Islamabad, Pakistan
Istanbul, Turkey
Izmir, Turkey
Jaipur, India
Jakarta, Indonesia
Jeddah, Saudi Arabia
Jerusalem, Israel
Jinan, China
Kabul, Afghanistan
Kagoshima, Japan
Kanpur, India
Kaohsiung, Taiwan
Karachi, Pakistan
Kolkata, India
Kuala Lumpur, Malaysia
Kumamoto, Japan
Kunming, China
Kuwait City, Kuwait
Lahore, Pakistan
Lucknow, India
Macau, China (SAR)
Manila, Philippines
Medan, Indonesia
Melbourne, Australia
Mumbai, India
Nagoya, Japan
Nagpur, India
Nanchang, China
Nanjing, China
Nanning, China
Nantong, China
Niigata, Japan
Ningbo, China
Okayama, Japan
Osaka–Kobe, Japan
Patna, India
Perth, Australia
Pune, India
Pyongyang, North Korea
Qingdao, China
Rangoon, Myanmar
Riyadh, Saudi Arabia
Sapporo, Japan
Sendai, Japan
Seoul, South Korea
Shanghai, China
Shantou, China
Shenyang, China
Shenzhen, China
Shijiazhuang, China
Shizuoka, Japan
Singapore, Singapore
Surat, India

Suzhou, China
Sydney, Australia
Taichung, Taiwan
Tainan, Taiwan
Taipei, Taiwan
Taiyuan, China
Tangshan, China
Taoyuan, Taiwan
Tehran, Iran
Tel Aviv, Israel
Tianjin, China
Tokyo, Japan
Visakhapatnam, India
Wenzhou, China
Wuhan, China
Wulumuqi, China
Wuxi, China
Xiamen, China
Xian, China
Xuzhou, China
Yantai, China
Zhengzhou, China
Zhongshan, China
Zhuhai, China
Zibo, China

B.2 Transportation costs for distribution center

In the table below we give the transportation costs per for allocating the alternative flow at alternative locations, this time including transport consolidations in this regional warehouse (fulfil orders from Cross docking and Stocked items together, warehouse functions as full Distribution center).

Set of locations	All flow	Flow for APAC customers	APAC supply to EMEA/AMER	All direct delivery
FlowNumbers	1-9	1-3,4	1,5-6	7-9
Orderlines		1.698	1.590	489
Best, The Netherlands	€42.766	€32.868	€3.382	€6.515
Kolkata, India	€24.719	€18.891	€2.791	€3.036
Patna, India	€24.961	€19.108	€2.813	€3.040
Visakhapatnam, India	€25.936	€19.204	€3.602	€3.129
Nagpur, India	€25.980	€19.224	€3.627	€3.128
Hyderabad, India	€25.983	€19.223	€3.630	€3.129
Chennai, India	€25.991	€19.223	€3.637	€3.130
Bangalore, India	€26.005	€19.238	€3.637	€3.130
Chongqing, China	€28.661	€18.586	€7.185	€2.888
Hong Kong, Hong Kong	€28.674	€17.770	€7.542	€3.361
Shenzhen, China	€28.674	€17.770	€7.542	€3.361
Best, The Netherlands	€42.766	€32.868	€3.382	€6.515
Hong Kong, Hong Kong	(€28.674)	(€17.770)	(€7.542)	(€3.361)
Proposed savings	€14.091	€15.097	(€4.159)	€3.153

Table 30: Transportation costs per location distribution center 1 year 5 months index-year 2017

B.3 Import costs

In the table below we provide import costs that would occur in 1 year and 5 months, starting in 2017.

		Purchasing value		Facility import tax		Final delivery tax		Total import tax paid	
Alternative	**Tariffs**	**StockLocation**	**DistributionCenter**	**StockLocation**	**DistributionCenter**	**StockLocation**	**DistributionCenter**	**StockLocation**	**DistributionCenter**
Order-lines		711	1698	711	1698	711	1698	711	1698
AU	2%	€154.289	€437.312	€3.085	€8.746	€1.424	€8.228	€4.510	€16.974
BN	0%	€154.289	€437.312	€0	€0	€7.710	€21.861	€7.710	€21.861
CN	4%	€154.289	€437.312	€6.171	€17.492	€7.465	€20.779	€13.636	€38.271
HK	0%	€154.289	€437.312	€0	€0	€7.547	€19.339	€7.547	€19.339
ID	7.5%	€154.289	€437.312	€11.571	€32.798	€7.170	€20.151	€18.742	€52.949
IN	5%	€154.289	€437.312	€7.714	€21.865	€7.709	€21.479	€15.424	€43.345
KH	0%	€154.289	€437.312	€0	€0	€7.666	€21.328	€7.666	€21.328
MM	5%	€154.289	€437.312	€7.714	€21.865	€0	€21.506	€7.714	€43.372
PH	1%	€154.289	€437.312	€1.542	€4.373	€0	€21.859	€1.542	€26.233
SG	0%	€154.289	€437.312	€0	€0	€7.617	€21.591	€7.617	€21.591
J	0%	€154.289	€437.312	€0	€0	€7.714	€21.866	€7.714	€21.866
TH	3%	€154.289	€437.312	€4.628	€13.119	€7.712	€21.823	€12.341	€34.943
TM	2%	€154.289	€437.312	€3.085	€8.746	€7.558	€21.340	€10.644	€30.086
TW	5%	€154.289	€437.312	€7.714	€21.865	€0	€21.601	€7.714	€43.467
VN	0%	€154.289	€437.312	€0	€0	€7.562	€21.427	€7.562	€21.427
NL	0%	€154.289	€437.312	€0	€0	€7.714	€21.865	€7.714	€21.865

Table 31: Import tax of 1 year 5 months demand from Asia-Pacific customers index-year 2017

B.4 Warehousing storage and throughput costs serve EMEA and AMER demand from Asia-Pacific suppliers by RW

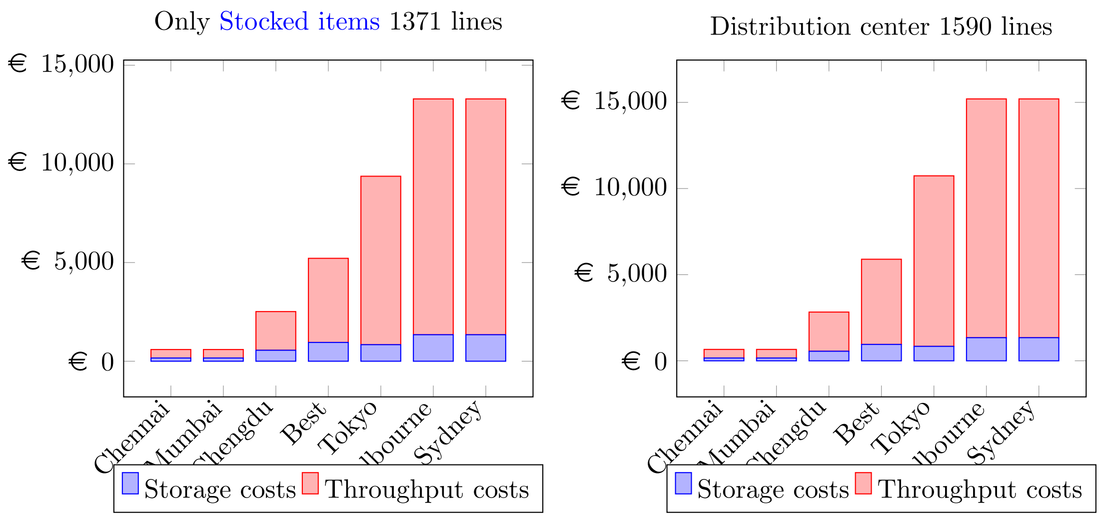

Figure 24: Warehousing storage and throughput costs Wrld demand Asia-Pacific suppliers 1y 5m

B.5 Warehousing storage and throughput costs serve DIRECT deliveries from suppliers by RW

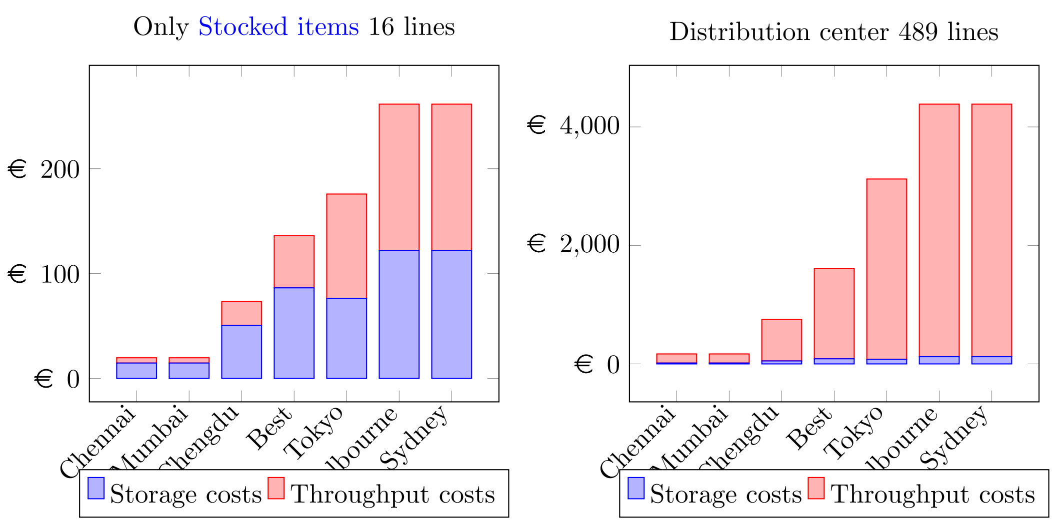

Figure 25: Warehousing storage and throughput costs DIRECT deliveries 1y 5m

B.6 Replenishment advise serve only Asia-Pacific demand by RW

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B.7 Replenishment advise serve EMEA and AMER demand from APAC suppliers by RW

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B.8 Replenishment advice direct shipment to APAC customer sites by RW

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B.9 Cost overview serving flow alternatives by regional warehouse facility

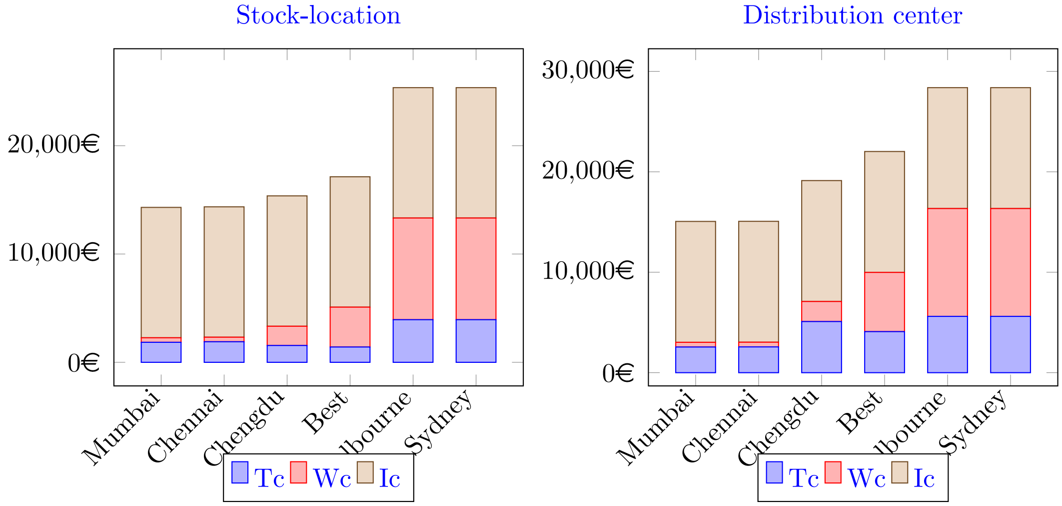

Figure 26: Yearly costs for serving EMEA and AMER demand APAC suppliers by RW index-year 2017

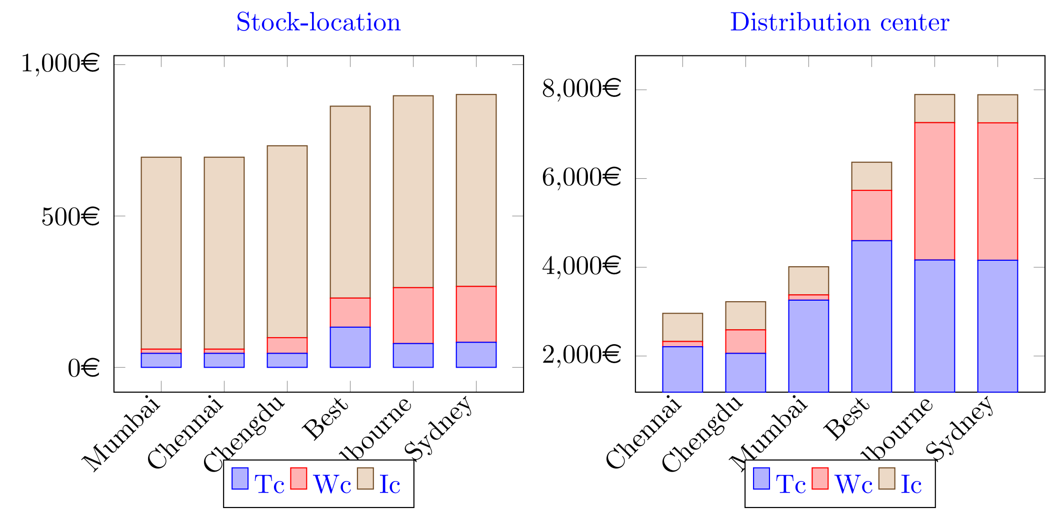

Figure 27: Yearly costs for serving current direct delivery to APAC by RW index-year 2017

B.10 Yearly costs and savings regional warehouse alternatives index-year 2017

APAC demand		Stock-location					Distribution center				
Ranking	**Set Locations**	Tc	Wc	Dc	Ic	Tot	Tc	Wc	Dc	Ic	Tot
1	Bangkok, Thailand	2413	702	8712	12296	24122	13020	1446	24666	12296	51427
2	Manila, Philippines	5263	321	6535	12296	24415	29974	659	18517	12296	61446
3	Best, Netherlands	4876	1927	5445	12296	24544	23201	4094	15434	12296	55025
4	Shenzhen, China	2370	931	9626	12296	25223	12544	1928	27015	12296	53783
5	Zhuhai, China	2372	931	9626	12296	25225	12561	1928	27015	12296	53800
6	Dongguan, China	2372	931	9626	12296	25225	12607	1928	27015	12296	53846
7	Zhongshan, China	2372	931	9626	12296	25225	12607	1928	27015	12296	53846
8	Foshan, China	2373	931	9626	12296	25226	12653	1928	27015	12296	53892
9	Guangzhou, China	2373	931	9626	12296	25226	12653	1928	27015	12296	53892
10	Changzhou, China	2375	931	9626	12296	25228	12716	1928	27015	12296	53955
11	Nanjing, China	2376	931	9626	12296	25229	12777	1928	27015	12296	54016
12	Shantou, China	2376	931	9626	12296	25229	12778	1928	27015	12296	54017
13	Xiamen, China	2376	931	9626	12296	25229	12777	1928	27015	12296	54016
14	Nanning, China	2378	931	9626	12296	25231	12762	1928	27015	12296	54001
15	Changsha, China	2390	931	9626	12296	25243	12884	1928	27015	12296	54123
16	Wuhan, China	2405	931	9626	12296	25258	12951	1928	27015	12296	54190
17	Wenzhou, China	2405	931	9626	12296	25258	12966	1928	27015	12296	54205
18	Fuzhou, China	2406	931	9626	12296	25259	12971	1928	27015	12296	54210
19	Nanchang, China	2406	931	9626	12296	25259	12967	1928	27015	12296	54206
20	Dongying, China	2406	931	9626	12296	25259	13237	1928	27015	12296	54476
21	Yantai, China	2406	931	9626	12296	25259	13236	1928	27015	12296	54475
22	Tangshan, China	2406	931	9626	12296	25260	13240	1928	27015	12296	54479
23	Tianjin, China	2406	931	9626	12296	25260	13240	1928	27015	12296	54479
24	Dalian, China	2407	931	9626	12296	25260	13237	1928	27015	12296	54476
25	Hefei, China	2411	931	9626	12296	25264	13221	1928	27015	12296	54460
26	Jinan, China	2411	931	9626	12296	25264	13222	1928	27015	12296	54461
27	Hangzhou, China	2412	931	9626	12296	25265	13220	1928	27015	12296	54459
28	Xuzhou, China	2413	931	9626	12296	25266	13241	1928	27015	12296	54480
29	Nantong, China	2413	931	9626	12296	25266	13232	1928	27015	12296	54471
30	Shanghai, China	2413	931	9626	12296	25267	13235	1928	27015	12296	54474
31	Ningbo, China	2414	931	9626	12296	25267	13235	1928	27015	12296	54474
32	Wuxi, China	2414	931	9626	12296	25267	13236	1928	27015	12296	54475
33	Zibo, China	2416	931	9626	12296	25269	13318	1928	27015	12296	54557
34	Qingdao, China	2416	931	9626	12296	25269	13321	1928	27015	12296	54560
35	Changchun, China	2417	931	9626	12296	25271	13814	1928	27015	12296	55053
51	Kolkata, India	2447	220	10888	12296	25850	13335	439	30597	12296	56667
52	Patna, India	2465	220	10888	12296	25869	13488	439	30597	12296	56820
53	Visakhapatnam, India	2472	220	10888	12296	25876	13556	439	30597	12296	56888
54	Nagpur, India	2472	220	10888	12296	25876	13570	439	30597	12296	56902
58	Melbourne, Australia	5704	4891	3184	12296	26076	31360	10964	11982	12296	66602
59	Sydney, Australia	5853	4891	3184	12296	26224	31825	10964	11982	12296	67067
60	Adelaide, Australia	5981	4891	3184	12296	26352	32573	10964	11982	12296	67815
61	Brisbane, Australia	6130	4891	3184	12296	26501	32988	10964	11982	12296	68230
62	Mumbai, India	3150	220	10888	12296	26554	17385	439	30597	12296	60717
63	Lucknow, India	3151	220	10888	12296	26554	17221	439	30597	12296	60552
64	Kanpur, India	3151	220	10888	12296	26555	17381	439	30597	12296	60713
65	Pune, India	3151	220	10888	12296	26555	17391	439	30597	12296	60722
66	Perth, Australia	6456	4891	3184	12296	26828	34486	10964	11982	12296	69728
69	Singapore, Singapore	5252	5551	5377	12296	28477	30130	12065	15241	12296	69732
71	Delhi, India	5580	220	10888	12296	28984	26483	439	30597	12296	69814
74	Jakarta, Indonesia	6122	432	13230	12296	32079	33193	866	37376	12296	83732

Table 32: Yearly costs regional warehouse alternative APAC demand index-year 2017

APAC demand		Stock-location					Distribution center				
Ranking	**Set Locations**	Tc	Wc	Dc	Ic	*Tot*	Tc	Wc	Dc	Ic	*Tot*
1	Bangkok, Thailand	2463	1225	-3266	0	422	10182	2648	-9232	0	3598
2	Manila, Philippines	-387	1606	-1089	0	129	-6773	3435	-3083	0	-6421
3	Best, Netherlands	0	0	0	0	0	0	0	0	0	0
4	Shenzhen, China	2506	995	-4181	0	-680	10657	2166	-11581	0	1242
5	Zhuhai, China	2504	995	-4181	0	-681	10640	2166	-11581	0	1225
6	Dongguan, China	2504	995	-4181	0	-681	10594	2166	-11581	0	1179
7	Zhongshan, China	2504	995	-4181	0	-681	10594	2166	-11581	0	1179
8	Foshan, China	2503	995	-4181	0	-683	10549	2166	-11581	0	1133
9	Guangzhou, China	2503	995	-4181	0	-683	10549	2166	-11581	0	1133
10	Changzhou, China	2500	995	-4181	0	-685	10485	2166	-11581	0	1070
11	Nanjing, China	2499	995	-4181	0	-686	10424	2166	-11581	0	1009
12	Shantou, China	2499	995	-4181	0	-686	10423	2166	-11581	0	1008
13	Xiamen, China	2499	995	-4181	0	-686	10424	2166	-11581	0	1009
14	Nanning, China	2498	995	-4181	0	-687	10439	2166	-11581	0	1024
15	Changsha, China	2486	995	-4181	0	-699	10317	2166	-11581	0	902
16	Wuhan, China	2471	995	-4181	0	-715	10250	2166	-11581	0	835
17	Wenzhou, China	2470	995	-4181	0	-715	10235	2166	-11581	0	820
18	Fuzhou, China	2470	995	-4181	0	-715	10230	2166	-11581	0	815
19	Nanchang, China	2470	995	-4181	0	-715	10235	2166	-11581	0	819
20	Dongying, China	2470	995	-4181	0	-716	9965	2166	-11581	0	549
21	Yantai, China	2469	995	-4181	0	-716	9965	2166	-11581	0	550
22	Tangshan, China	2469	995	-4181	0	-716	9962	2166	-11581	0	546
23	Tianjin, China	2469	995	-4181	0	-716	9962	2166	-11581	0	546
24	Dalian, China	2469	995	-4181	0	-716	9964	2166	-11581	0	549
25	Hefei, China	2465	995	-4181	0	-720	9980	2166	-11581	0	565
26	Jinan, China	2464	995	-4181	0	-721	9980	2166	-11581	0	564
27	Hangzhou, China	2463	995	-4181	0	-722	9981	2166	-11581	0	566
28	Xuzhou, China	2463	995	-4181	0	-722	9960	2166	-11581	0	545
29	Nantong, China	2462	995	-4181	0	-723	9969	2166	-11581	0	554
30	Shanghai, China	2462	995	-4181	0	-723	9966	2166	-11581	0	551
31	Ningbo, China	2462	995	-4181	0	-723	9966	2166	-11581	0	551
32	Wuxi, China	2462	995	-4181	0	-723	9966	2166	-11581	0	550
33	Zibo, China	2460	995	-4181	0	-725	9883	2166	-11581	0	468
34	Qingdao, China	2460	995	-4181	0	-725	9880	2166	-11581	0	465
35	Changchun, China	2458	995	-4181	0	-727	9387	2166	-11581	0	-28
51	Kolkata, India	2429	1707	-5443	0	-1307	9866	3655	-15163	0	-1642
52	Patna, India	2410	1707	-5443	0	-1325	9713	3655	-15163	0	-1795
53	Visakhapatnam, India	2404	1707	-5443	0	-1332	9645	3655	-15163	0	-1863
54	Nagpur, India	2404	1707	-5443	0	-1332	9631	3655	-15163	0	-1877
58	Melbourne, Australia	-829	-2965	2261	0	-1532	-8158	-6870	3452	0	-11577
59	Sydney, Australia	-977	-2965	2261	0	-1681	-8624	-6870	3452	0	-12042
60	Adelaide, Australia	-1105	-2965	2261	0	-1809	-9371	-6870	3452	0	-12790
61	Brisbane, Australia	-1254	-2965	2261	0	-1958	-9787	-6870	3452	0	-13205
62	Mumbai, India	1725	1707	-5443	0	-2011	5816	3655	-15163	0	-5692
63	Lucknow, India	1725	1707	-5443	0	-2011	5981	3655	-15163	0	-5527
64	Kanpur, India	1725	1707	-5443	0	-2011	5820	3655	-15163	0	-5688
65	Pune, India	1724	1707	-5443	0	-2011	5811	3655	-15163	0	-5697
66	Perth, Australia	-1581	-2965	2261	0	-2284	-11284	-6870	3452	0	-14703
69	Singapore, Singapore	-377	-3624	68	0	-3933	-6928	-7972	193	0	-14707
71	Delhi, India	-704	1707	-5443	0	-4440	-3281	3655	-15163	0	-14789
74	Jakarta, Indonesia	-1246	1495	-7785	0	-7536	-9992	3228	-21942	0	-28707

Table 33: Yearly savings regional warehouse alternative APAC demand index-year 2017

All decomposed flow		Stock-location					Distribution center				
Ranking	**Set Locations**	Tc	Wc	Dc	Ic	*Tot*	Tc	Wc	Dc	Ic	*Tot*
1	Bangkok, Thailand	4821	2078	8712	24967	40577	21269	3344	24666	24967	74246
2	Manila, Philippines	8937	951	6535	24967	41390	40266	1525	18517	24967	85276
3	Best, Netherlands	6423	5704	5445	24967	42538	30188	9389	15434	24967	79979
4	Shenzhen, China	4475	2759	9626	24967	41827	20241	4454	27015	24967	76677
5	Zhuhai, China	3753	2759	9626	24967	41104	20259	4454	27015	24967	76695
6	Dongguan, China	4481	2759	9626	24967	41832	20306	4454	27015	24967	76742
7	Zhongshan, China	3753	2759	9626	24967	41104	20304	4454	27015	24967	76740
8	Foshan, China	4482	2759	9626	24967	41834	20351	4454	27015	24967	76787
9	Guangzhou, China	4482	2759	9626	24967	41834	20351	4454	27015	24967	76787
10	Changzhou, China	4484	2759	9626	24967	41836	20418	4454	27015	24967	76853
11	Nanjing, China	4481	2759	9626	24967	41833	20503	4454	27015	24967	76939
12	Shantou, China	4481	2759	9626	24967	41833	20484	4454	27015	24967	76920
13	Xiamen, China	4481	2759	9626	24967	41833	20503	4454	27015	24967	76939
14	Nanning, China	4487	2759	9626	24967	41839	20471	4454	27015	24967	76907
15	Changsha, China	4386	2759	9626	24967	41738	20250	4454	27015	24967	76686
16	Wuhan, China	4470	2759	9626	24967	41821	20373	4454	27015	24967	76809
17	Wenzhou, China	4494	2759	9626	24967	41845	20693	4454	27015	24967	77129
18	Fuzhou, China	4501	2759	9626	24967	41853	20701	4454	27015	24967	77137
19	Nanchang, China	4505	2759	9626	24967	41857	20676	4454	27015	24967	77111
20	Dongying, China	4138	2759	9626	24967	41490	20687	4454	27015	24967	77123
21	Yantai, China	3674	2759	9626	24967	41026	20683	4454	27015	24967	77119
22	Tangshan, China	4139	2759	9626	24967	41490	20688	4454	27015	24967	77123
23	Tianjin, China	4139	2759	9626	24967	41490	20690	4454	27015	24967	77126
24	Dalian, China	4139	2759	9626	24967	41490	20685	4454	27015	24967	77121
25	Hefei, China	4457	2759	9626	24967	41809	20642	4454	27015	24967	77078
26	Jinan, China	4476	2759	9626	24967	41827	20643	4454	27015	24967	77079
27	Hangzhou, China	4505	2759	9626	24967	41857	20949	4454	27015	24967	77385
28	Xuzhou, China	3681	2759	9626	24967	41032	20684	4454	27015	24967	77120
29	Nantong, China	4506	2759	9626	24967	41858	20977	4454	27015	24967	77413
30	Shanghai, China	4506	2759	9626	24967	41858	20980	4454	27015	24967	77416
31	Ningbo, China	4506	2759	9626	24967	41858	20981	4454	27015	24967	77416
32	Wuxi, China	4507	2759	9626	24967	41858	20981	4454	27015	24967	77417
33	Zibo, China	3369	2759	9626	24967	40720	20762	4454	27015	24967	77198
34	Qingdao, China	4463	2759	9626	24967	41814	20770	4454	27015	24967	77206
35	Changchun, China	4378	2759	9626	24967	41729	21854	4454	27015	24967	78290
51	Kolkata, India	4065	652	10888	24967	40572	17449	1025	30597	24967	74037
52	Patna, India	4035	652	10888	24967	40542	17620	1025	30597	24967	74209
53	Visakhapatnam, India	4367	652	10888	24967	40874	18308	1025	30597	24967	74897
54	Nagpur, India	4345	652	10888	24967	40852	18339	1025	30597	24967	74928
58	Melbourne, Australia	9720	14459	3184	24967	52330	41131	24789	11982	24967	102870
59	Sydney, Australia	9872	14459	3184	24967	52482	41592	24789	11982	24967	103330
60	Adelaide, Australia	10000	14459	3184	24967	52610	42522	24789	11982	24967	104260
61	Brisbane, Australia	10154	14459	3184	24967	52764	42933	24789	11982	24967	104671
62	Mumbai, India	5046	652	10888	24967	41553	23200	1025	30597	24967	79789
63	Lucknow, India	5047	652	10888	24967	41554	23043	1025	30597	24967	79631
64	Kanpur, India	5047	652	10888	24967	41554	23203	1025	30597	24967	79792
65	Pune, India	5046	652	10888	24967	41553	23210	1025	30597	24967	79799
69	Singapore, Singapore	8866	16423	5377	24967	55633	40102	27504	15241	24967	107815
71	Delhi, India	7529	652	10888	24967	44036	33296	1025	30597	24967	89885
74	Jakarta, Indonesia	9976	1280	13230	24967	49452	43486	2019	37376	24967	107848

Table 34: Yearly costs regional warehouse alternative all flow index-year 2017

All decomposed flow		**Stock-location**					**Distribution center**				
Ranking	**Set Locations**	Tc	Wc	Dc	Ic	*Tot*	Tc	Wc	Dc	Ic	*Tot*
1	Bangkok, Thailand	1602	3625	-3266	0	1961	8919	6045	-9232	0	5732
2	Manila, Philippines	-2515	4752	-1089	0	1148	-10078	7864	-3083	0	-5297
3	Best, Netherlands	0	0	0	0	0	0	0	0	0	0
4	Shenzhen, China	1947	2945	-4181	0	711	9947	4936	-11581	0	3302
5	Zhuhai, China	2670	2945	-4181	0	1434	9929	4936	-11581	0	3284
6	Dongguan, China	1942	2945	-4181	0	706	9882	4936	-11581	0	3237
7	Zhongshan, China	2670	2945	-4181	0	1434	9884	4936	-11581	0	3238
8	Foshan, China	1940	2945	-4181	0	705	9837	4936	-11581	0	3191
9	Guangzhou, China	1940	2945	-4181	0	705	9837	4936	-11581	0	3191
10	Changzhou, China	1938	2945	-4181	0	702	9771	4936	-11581	0	3125
11	Nanjing, China	1941	2945	-4181	0	705	9685	4936	-11581	0	3040
12	Shantou, China	1941	2945	-4181	0	705	9704	4936	-11581	0	3059
13	Xiamen, China	1941	2945	-4181	0	705	9685	4936	-11581	0	3040
14	Nanning, China	1935	2945	-4181	0	699	9717	4936	-11581	0	3072
15	Changsha, China	2037	2945	-4181	0	801	9938	4936	-11581	0	3293
16	Wuhan, China	1953	2945	-4181	0	717	9815	4936	-11581	0	3170
17	Wenzhou, China	1929	2945	-4181	0	693	9495	4936	-11581	0	2850
18	Fuzhou, China	1921	2945	-4181	0	686	9487	4936	-11581	0	2842
19	Nanchang, China	1917	2945	-4181	0	681	9513	4936	-11581	0	2867
20	Dongying, China	2284	2945	-4181	0	1048	9501	4936	-11581	0	2856
21	Yantai, China	2748	2945	-4181	0	1512	9505	4936	-11581	0	2860
22	Tangshan, China	2284	2945	-4181	0	1048	9501	4936	-11581	0	2855
23	Tianjin, China	2284	2945	-4181	0	1048	9498	4936	-11581	0	2853
24	Dalian, China	2284	2945	-4181	0	1048	9503	4936	-11581	0	2858
25	Hefei, China	1965	2945	-4181	0	729	9547	4936	-11581	0	2901
26	Jinan, China	1947	2945	-4181	0	711	9545	4936	-11581	0	2900
27	Hangzhou, China	1918	2945	-4181	0	682	9239	4936	-11581	0	2594
28	Xuzhou, China	2742	2945	-4181	0	1506	9504	4936	-11581	0	2859
29	Nantong, China	1917	2945	-4181	0	681	9211	4936	-11581	0	2566
30	Shanghai, China	1916	2945	-4181	0	680	9208	4936	-11581	0	2563
31	Ningbo, China	1916	2945	-4181	0	680	9208	4936	-11581	0	2562
32	Wuxi, China	1916	2945	-4181	0	680	9207	4936	-11581	0	2562
33	Zibo, China	3054	2945	-4181	0	1818	9426	4936	-11581	0	2780
34	Qingdao, China	1960	2945	-4181	0	724	9418	4936	-11581	0	2773
35	Changchun, China	2045	2945	-4181	0	809	8334	4936	-11581	0	1689
51	Kolkata, India	2357	5051	-5443	0	1966	12739	8365	-15163	0	5941
52	Patna, India	2387	5051	-5443	0	1996	12568	8365	-15163	0	5770
53	Visakhapatnam, India	2055	5051	-5443	0	1664	11880	8365	-15163	0	5082
54	Nagpur, India	2078	5051	-5443	0	1687	11849	8365	-15163	0	5051
58	Melbourne, Australia	-3297	-8756	2261	0	-9791	-10943	-15400	3452	0	-22891
59	Sydney, Australia	-3449	-8756	2261	0	-9944	-11404	-15400	3452	0	-23351
60	Adelaide, Australia	-3578	-8756	2261	0	-10072	-12333	-15400	3452	0	-24281
61	Brisbane, Australia	-3731	-8756	2261	0	-10225	-12745	-15400	3452	0	-24692
62	Mumbai, India	1377	5051	-5443	0	986	6988	8365	-15163	0	190
63	Lucknow, India	1376	5051	-5443	0	984	7146	8365	-15163	0	348
64	Kanpur, India	1375	5051	-5443	0	984	6985	8365	-15163	0	187
65	Pune, India	1376	5051	-5443	0	985	6978	8365	-15163	0	180
69	Singapore, Singapore	-2444	-10719	68	0	-13095	-9914	-18115	193	0	-27836
71	Delhi, India	-1106	5051	-5443	0	-1497	-3108	8365	-15163	0	-9906
74	Jakarta, Indonesia	-3553	4424	-7785	0	-6914	-13298	7371	-21942	0	-27869

Table 35: Yearly savings regional warehouse alternative all flow index-year 2017

B.11 Future costs and savings for setting up a regional warehouse

Forecast	**Forecast FY**	**2018**	**2018**	**2019**	**2019**	**2022**	**2022**
APAC demand	**WarehouseFunction**	**Stock-location**	**Distribution center**	**Stock-location**	**Distribution center**	**Stock-location**	**Distribution center**
Ranking(2017)	**Set Locations**	Total	Total	Total	Total	Total	Total
1	Bangkok, Thailand	27074	59075	28412	62684	32831	73917
2	Manila, Philippines	27417	70817	28780	75260	33272	88992
3	Best, Netherlands	27568	63291	28942	67200	33466	79330
4	Shenzhen, China	28365	61836	29794	65641	34488	77461
5	Zhuhai, China	28367	61856	29797	65663	34491	77488
6	Dongguan, China	28367	61910	29797	65720	34491	77556
7	Zhongshan, China	28367	61909	29797	65720	34491	77556
8	Foshan, China	28368	61963	29798	65777	34493	77625
9	Guangzhou, China	28368	61963	29798	65777	34493	77625
10	Changzhou, China	28371	62037	29801	65857	34496	77721
11	Nanjing, China	28372	62109	29802	65934	34498	77812
12	Shantou, China	28372	62110	29802	65935	34498	77814
13	Xiamen, China	28372	62109	29802	65934	34498	77812
14	Nanning, China	28374	62091	29804	65915	34500	77789
15	Changsha, China	28388	62234	29819	66068	34518	77973
16	Wuhan, China	28406	62313	29838	66152	34541	78074
17	Wenzhou, China	28406	62330	29839	66171	34541	78097
18	Fuzhou, China	28407	62336	29840	66177	34542	78104
19	Nanchang, China	28407	62331	29840	66172	34542	78097
20	Dongying, China	28407	62647	29840	66511	34543	78504
21	Yantai, China	28407	62646	29840	66510	34543	78502
22	Tangshan, China	28407	62651	29840	66514	34543	78508
23	Tianjin, China	28407	62651	29840	66514	34543	78508
24	Dalian, China	28408	62648	29841	66511	34543	78504
25	Hefei, China	28413	62629	29846	66491	34550	78480
26	Jinan, China	28413	62630	29846	66491	34550	78481
27	Hangzhou, China	28414	62628	29847	66489	34552	78478
28	Xuzhou, China	28415	62652	29848	66516	34552	78510
29	Nantong, China	28415	62642	29849	66504	34553	78496
30	Shanghai, China	28416	62645	29849	66508	34554	78501
31	Ningbo, China	28416	62645	29849	66508	34554	78501
32	Wuxi, China	28416	62646	29849	66509	34554	78502
33	Zibo, China	28418	62743	29852	66613	34557	78626
34	Qingdao, China	28418	62746	29852	66617	34557	78631
35	Changchun, China	28420	63324	29854	67235	34560	79372
51	Kolkata, India	29100	65215	30582	69260	35432	81800
52	Patna, India	29121	65395	30605	69453	35460	82031
53	Visakhapatnam, India	29129	65474	30613	69538	35470	82133
54	Nagpur, India	29129	65491	30614	69556	35470	82154
58	Melbourne, Australia	29364	76858	30865	81730	35771	96749
59	Sydney, Australia	29538	77404	31051	82315	35994	97450
60	Adelaide, Australia	29688	78280	31212	83253	36187	98574
61	Brisbane, Australia	29863	78767	31399	83774	36412	99199
62	Mumbai, India	29925	69962	31465	74344	36491	87894
65	Pune, India	29925	69968	31466	74351	36492	87903
66	Perth, Australia	30245	80522	31809	85654	36903	101453
69	Singapore, Singapore	32178	80528	33878	85660	39384	101460
71	Delhi, India	32772	80624	34514	85763	40147	101583
74	Jakarta, Indonesia	36400	96934	38400	103231	44804	122524

Table 36: Forecasted costs of serving APAC demand by alternative warehouse locations and functions

Forecast	Forecast FY	2018	2018	2019	2019	2022	2022
APAC demand	**WarehouseFunction**	**Stock-location**	**Distribution center**	**Stock-location**	**Distribution center**	**Stock-location**	**Distribution center**
Ranking(2017)	**Set Locations**	Total	Total	Total	Total	Total	Total
1	Bangkok, Thailand	494	4216	530	4516	635	5413
2	Manila, Philippines	151	-7526	162	-8060	194	-9662
3	Best, Netherlands	0	0	0	0	0	0
4	Shenzhen, China	-797	1455	-852	1559	-1022	1869
5	Zhuhai, China	-799	1435	-855	1537	-1025	1842
6	Dongguan, China	-799	1381	-855	1480	-1025	1774
7	Zhongshan, China	-799	1382	-855	1480	-1025	1774
8	Foshan, China	-800	1328	-856	1423	-1027	1705
9	Guangzhou, China	-800	1328	-856	1423	-1027	1705
10	Changzhou, China	-803	1254	-859	1343	-1030	1609
11	Nanjing, China	-804	1182	-860	1266	-1032	1518
12	Shantou, China	-804	1181	-860	1265	-1032	1516
13	Xiamen, China	-804	1182	-860	1266	-1032	1518
14	Nanning, China	-806	1200	-862	1285	-1034	1541
15	Changsha, China	-820	1057	-877	1132	-1052	1357
16	Wuhan, China	-838	978	-896	1048	-1075	1256
17	Wenzhou, China	-838	961	-897	1029	-1075	1233
18	Fuzhou, China	-839	955	-898	1023	-1076	1226
19	Nanchang, China	-839	960	-898	1028	-1076	1233
20	Dongying, China	-839	644	-898	689	-1077	826
21	Yantai, China	-839	645	-898	690	-1077	828
22	Tangshan, China	-839	640	-898	686	-1077	822
23	Tianjin, China	-839	640	-898	686	-1077	822
24	Dalian, China	-840	643	-899	689	-1077	826
25	Hefei, China	-845	662	-904	709	-1084	850
26	Jinan, China	-845	661	-904	709	-1084	849
27	Hangzhou, China	-846	663	-905	711	-1086	852
28	Xuzhou, China	-847	639	-906	684	-1086	820
29	Nantong, China	-847	649	-907	696	-1087	834
30	Shanghai, China	-848	646	-907	692	-1088	829
31	Ningbo, China	-848	646	-907	692	-1088	829
32	Wuxi, China	-848	645	-907	691	-1088	828
33	Zibo, China	-850	548	-910	587	-1091	704
34	Qingdao, China	-850	545	-910	583	-1091	699
35	Changchun, China	-852	-33	-912	-35	-1094	-42
51	Kolkata, India	-1532	-1924	-1640	-2060	-1966	-2470
52	Patna, India	-1553	-2104	-1663	-2253	-1994	-2701
53	Visakhapatnam, India	-1561	-2183	-1671	-2338	-2004	-2803
54	Nagpur, India	-1561	-2200	-1672	-2356	-2004	-2824
58	Melbourne, Australia	-1796	-13567	-1923	-14530	-2305	-17419
59	Sydney, Australia	-1970	-14113	-2109	-15115	-2528	-18120
60	Adelaide, Australia	-2120	-14989	-2270	-16053	-2721	-19244
61	Brisbane, Australia	-2295	-15476	-2457	-16574	-2946	-19869
62	Mumbai, India	-2357	-6671	-2523	-7144	-3025	-8564
65	Pune, India	-2357	-6677	-2524	-7151	-3026	-8573
66	Perth, Australia	-2677	-17231	-2867	-18454	-3437	-22123
69	Singapore, Singapore	-4610	-17237	-4936	-18460	-5918	-22130
71	Delhi, India	-5204	-17333	-5572	-18563	-6681	-22253
74	Jakarta, Indonesia	-8832	-33643	-9458	-36031	-11338	-43194

Table 37: Forecasted savings of alternative warehouse locations and functions serving APAC demand

B.12 Order-line fulfillment serving EMEA and AMER demand from APAC suppliers by RW

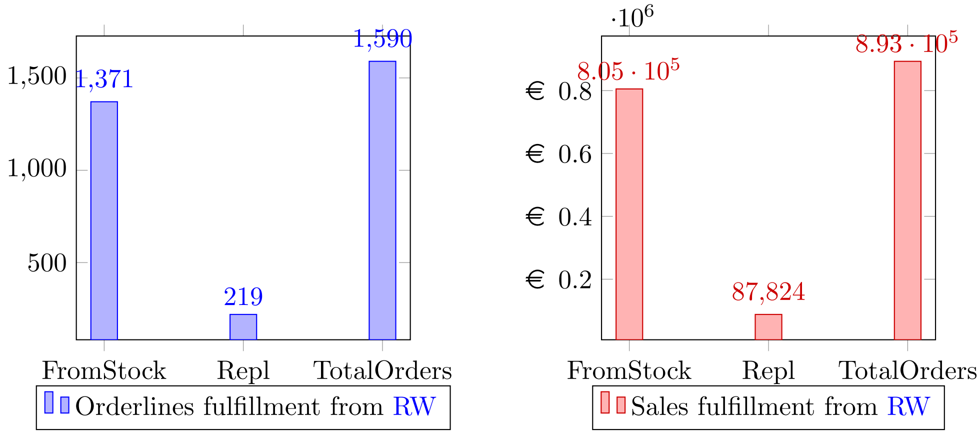

Figure 28: APAC supplier - RW - EMEA and AMER customers 01-01-17 - 31-05-18

EMEA and AMER demand by Asia-Pacific suppliers represents a significant amount Order-lines to be delivered directly from stock, however this would stay the same of course when handling by the central warehouse in Best.

B.13 Order-line fulfilment APAC demand in sales from stock at regional warehouse

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B.14 Criticality parts in regional warehouse

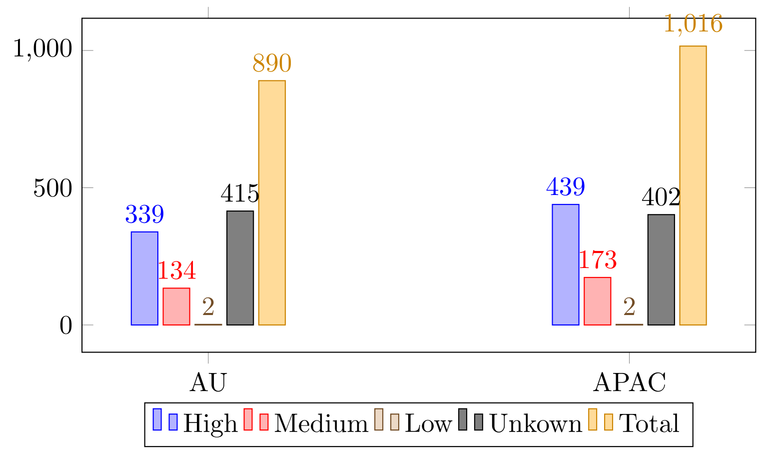

Figure 29: WPP criticality of orderlines via GDC 01-01-17 - 31-05-18

Parameters	**Replenishment flow for APAC customers**	**(Packages flow for APAC)**
FlowNumbers	1-3,4	1-3,4
# Stocked items	110	307
Highly critically	36	67
Medium critically	10	76
Low critically	0	3
Not available	64	161

Table 38: Criticality stock keeping items Repl. parts and packages

B.15 AHP weight of objectives

B.15.1 Weight of objectives by Frank van Schijndel

Prioritization criteria																
COSTS	8	7	6	5	4	3	2	1	2	3	**4**	5	6	7	8	POTENTIAL
COSTS	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	LEAD-TIME
COSTS	8	7	6	5	4	3	2	1	2	**3**	4	5	6	7	8	ORDER FULFILLMENT
COSTS	**8**	7	6	5	4	3	2	1	2	3	4	5	6	7	8	EXCHANGE RATE STABILITY
COSTS	8	7	6	5	4	3	2	1	2	3	4	5	6	7	**8**	POLITICAL RISK INDEX
COSTS	8	7	6	5	4	3	2	1	2	3	4	**5**	6	7	8	DANGEROUS GOODS
COSTS	8	7	6	5	4	3	2	1	**2**	3	4	5	6	7	8	CRITICALITY PARTS
POTENTIAL	8	7	6	5	4	3	2	1	2	3	4	**5**	6	7	8	LEAD-TIME
POTENTIAL	8	7	6	5	4	3	2	1	2	3	4	**5**	6	7	8	ORDER FULFILLMENT
POTENTIAL	8	7	**6**	5	4	3	2	1	2	3	4	5	6	7	8	EXCHANGE RATE STABILITY
POTENTIAL	8	7	6	5	4	3	2	1	2	3	4	5	6	7	**8**	POLITICAL RISK INDEX
POTENTIAL	8	7	6	5	4	3	2	1	2	3	4	5	6	7	**8**	DANGEROUS GOODS
POTENTIAL	8	7	6	**5**	4	3	2	1	2	3	4	5	6	7	8	CRITICALITY PARTS
LEAD-TIME	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	ORDER FULFILLMENT
LEAD-TIME	8	7	6	5	**4**	3	2	1	2	3	4	5	6	7	8	EXCHANGE RATE STABILITY
LEAD-TIME	8	7	6	5	4	3	2	1	2	3	4	5	6	7	**8**	POLITICAL RISK INDEX
LEAD-TIME	8	7	6	5	4	3	2	1	2	3	4	5	6	7	**8**	DANGEROUS GOODS
LEAD-TIME	8	7	6	**5**	4	3	2	1	2	3	4	5	6	7	8	CRITICALITY PARTS
ORDER FULFILLMENT	8	7	6	5	4	3	**2**	1	2	3	4	5	6	7	8	EXCHANGE RATE STABILITY
ORDER FULFILLMENT	8	7	6	5	4	3	2	1	2	3	4	5	6	7	**8**	POLITICAL RISK INDEX
ORDER FULFILLMENT	8	7	6	5	4	3	2	1	2	3	4	5	6	7	**8**	DANGEROUS GOODS
ORDER FULFILLMENT	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	CRITICALITY PARTS
EXCHANGE RATE STABILITY	8	7	6	5	4	3	2	1	2	3	4	5	6	7	**8**	POLITICAL RISK INDEX
EXCHANGE RATE STABILITY	8	7	6	5	4	3	2	1	2	3	4	5	6	7	**8**	DANGEROUS GOODS
EXCHANGE RATE STABILITY	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	CRITICALITY PARTS
POLITICAL RISK INDEX	**8**	7	6	5	4	3	2	1	2	3	4	5	6	7	8	DANGEROUS GOODS
POLITICAL RISK INDEX	**8**	7	6	5	4	3	2	1	2	3	4	5	6	7	8	CRITICALITY PARTS
DANGEROUS GOODS	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	CRITICALITY PARTS

Table 39: Prioritization Frank van Schijndel - Global Spare Parts Manager

Finding w_{max}.

Step 1 A and A_{norm}.

$$\text{When A} = \begin{array}{c} \\ Costs \\ Potential \\ Lead-time \\ Fulfilment \\ Exchange \\ Political \\ DG \\ Criticality \end{array} \begin{array}{c} \begin{array}{cccccccc} Costs & Potential & Lead-time & Fulfilment & Exchange & Political & DG & Criticality \end{array} \\ \begin{pmatrix} 1 & \frac{1}{4} & 1 & \frac{1}{3} & 8 & \frac{1}{8} & \frac{1}{5} & \frac{1}{2} \\ 4 & 1 & \frac{1}{5} & \frac{1}{5} & 6 & \frac{1}{8} & \frac{1}{8} & 5 \\ 1 & 5 & 1 & 1 & 4 & \frac{1}{8} & \frac{1}{8} & 5 \\ 3 & 5 & 1 & 1 & 2 & \frac{1}{8} & \frac{1}{8} & 1 \\ \frac{1}{8} & \frac{1}{6} & \frac{1}{4} & \frac{1}{2} & 1 & \frac{1}{8} & \frac{1}{8} & \frac{1}{7} \\ 8 & 8 & 8 & 8 & 8 & 1 & 8 & 8 \\ 5 & 8 & 8 & 8 & 8 & \frac{1}{8} & 1 & 1 \\ 2 & \frac{1}{5} & \frac{1}{8} & 1 & 7 & \frac{1}{8} & 1 & 1 \end{pmatrix} \end{array}$$

$$\text{A}_{normalized} = \begin{array}{c} \\ Costs \\ Potential \\ Lead-time \\ Fulfilment \\ Exchange \\ Political \\ DG \\ Criticality \end{array} \begin{array}{c} \begin{array}{cccccccc} Costs & Potential & Lead-time & Fulfilment & Exchange & Political & DG & Criticality \end{array} \\ \begin{pmatrix} 0.041 & 0.009 & 0.051 & 0.017 & 0.182 & 0.067 & 0.019 & 0.0229 \\ 0.166 & 0.036 & 0.01 & 0.01 & 0.136 & 0.067 & 0.012 & 0.231 \\ 0.041 & 0.181 & 0.051 & 0.05 & 0.091 & 0.067 & 0.012 & 0.231 \\ 0.124 & 0.181 & 0.051 & 0.05 & 0.044 & 0.067 & 0.012 & 0.046 \\ 0.005 & 0.006 & 0.013 & 0.025 & 0.022 & 0.067 & 0.012 & 0.007 \\ 0.332 & 0.289 & 0.406 & 0.399 & 0.1819 & 0.533 & 0.748 & 0.37 \\ 0.206 & 0.029 & 0.406 & 0.399 & 0.182 & 0.067 & 0.092 & 0.046 \\ 0.083 & 0.007 & 0.01 & 0.05 & 0.159 & 0.067 & 0.093 & 0.045 \end{pmatrix} \end{array}$$

Step 2 w_{max}. $w_1 = .051$ for objective 1 (costs), $w_2 = .083$ for objective 2 (potential), $w_3 = .090$ for objective 3 (Lead-time), $w_4 = .072$ for objective 4 (fulfilment), $w_5 = .019$ for objective 5 (exchange rates), $w_6 = .407$ for objective 6 (Fufilment), $w_7 = .211$ for objective 7 (dangerous goods) and $w_8 = .064$ for objective 8 (criticality parts).

Checking for consistency
Step 1 Compute Aw^T.

$$Aw^T = \begin{bmatrix} 1 & \frac{1}{4} & 1 & \frac{1}{3} & 8 & \frac{1}{8} & \frac{1}{5} & \frac{1}{2} \\ 4 & 1 & \frac{1}{5} & \frac{1}{5} & 6 & \frac{1}{8} & \frac{1}{8} & 5 \\ 1 & 5 & 1 & 1 & 4 & \frac{1}{8} & \frac{1}{8} & 5 \\ 3 & 5 & 1 & 1 & 2 & \frac{1}{8} & \frac{1}{8} & 1 \\ \frac{1}{8} & \frac{1}{6} & \frac{1}{4} & \frac{1}{2} & 1 & \frac{1}{8} & \frac{1}{8} & \frac{1}{7} \\ 8 & 8 & 8 & 8 & 8 & 1 & 8 & 8 \\ 5 & 8 & 8 & 8 & 8 & \frac{1}{8} & 1 & 1 \\ 2 & \frac{1}{5} & \frac{1}{8} & 1 & 7 & \frac{1}{8} & 1 & 1 \end{bmatrix} \begin{bmatrix} 0.051 \\ 0.083 \\ 0.090 \\ 0.072 \\ 0.019 \\ 0.407 \\ 0.211 \\ 0.064 \end{bmatrix} = \begin{bmatrix} 0.468 \\ 0.837 \\ 1.108 \\ 0.914 \\ 0.185 \\ 5.147 \\ 2.706 \\ 0.672 \end{bmatrix}$$

Step 2 Compute consistency index (CI) as follows:

$$\frac{1}{8}\left[\frac{0.468}{0.051} + \frac{0.837}{0.083} + \frac{1.108}{0.090} + \frac{0.914}{0.072} + \frac{0.185}{0.019} + \frac{5.147}{0.407} + \frac{2.706}{0.211} + \frac{0.672}{0.064}\right] = 11.185 \quad (15)$$

CI $= \frac{11.185-n}{n-1} = \frac{11.185-8}{7} = 0.455$

Step 3 In our AHP the $\frac{CI}{RI}$ ratio is 0.31.

Optimal alternative:
Melbourne, Australia
Distribution center
APAC flow
WP&P

B.15.2 Weight of objectives by Stefan van Venrooij

Prioritization criteria																
COSTS	8	7	6	5	4	3	2	1	2	3	4	**5**	6	7	8	POTENTIAL
COSTS	8	7	6	5	4	3	2	1	2	3	4	5	**6**	7	8	LEAD-TIME
COSTS	8	7	6	5	4	3	2	1	2	3	4	5	**6**	7	8	ORDER FULFILLMENT
COSTS	8	7	6	5	4	3	2	1	**2**	3	4	5	6	7	8	EXCHANGE RATE STABILITY
COSTS	8	7	6	5	4	3	2	1	2	3	**4**	5	6	7	8	POLITICAL RISK INDEX
COSTS	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	DANGEROUS GOODS
COSTS	8	7	6	5	4	3	2	1	2	3	**4**	5	6	7	8	CRITICALITY PARTS
POTENTIAL	8	7	6	5	4	3	2	1	2	3	4	5	**6**	7	8	LEAD-TIME
POTENTIAL	8	7	6	5	4	3	2	1	2	3	4	5	**6**	7	8	ORDER FULFILLMENT
POTENTIAL	**8**	7	6	5	4	3	2	1	2	3	4	5	6	7	8	EXCHANGE RATE STABILITY
POTENTIAL	**8**	7	6	5	4	3	2	1	2	3	4	5	6	7	8	POLITICAL RISK INDEX
POTENTIAL	8	7	6	5	4	3	2	1	**2**	3	4	5	6	7	8	DANGEROUS GOODS
POTENTIAL	8	7	6	5	4	3	2	1	2	3	**4**	5	6	7	8	CRITICALITY PARTS
LEAD-TIME	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	ORDER FULFILLMENT
LEAD-TIME	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	EXCHANGE RATE STABILITY
LEAD-TIME	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	POLITICAL RISK INDEX
LEAD-TIME	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	DANGEROUS GOODS
LEAD-TIME	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	CRITICALITY PARTS
ORDER FULFILLMENT	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	EXCHANGE RATE STABILITY
ORDER FULFILLMENT	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	POLITICAL RISK INDEX
ORDER FULFILLMENT	8	7	6	5	**4**	3	2	1	2	3	4	5	6	7	8	DANGEROUS GOODS
ORDER FULFILLMENT	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	CRITICALITY PARTS
EXCHANGE RATE STABILITY	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	POLITICAL RISK INDEX
EXCHANGE RATE STABILITY	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	DANGEROUS GOODS
EXCHANGE RATE STABILITY	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	CRITICALITY PARTS
POLITICAL RISK INDEX	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	DANGEROUS GOODS
POLITICAL RISK INDEX	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	CRITICALITY PARTS
DANGEROUS GOODS	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	CRITICALITY PARTS

Table 40: Prioritization Stefan van Venrooij - Manager Logistical Support

Finding w_{max}.

Step 1 A and A_{norm}.

$$\text{When A} = \begin{array}{c} \\ Costs \\ Potential \\ Lead{-}time \\ Fulfilment \\ Exchange \\ Political \\ DG \\ Criticality \end{array} \begin{array}{cccccccc} Costs & Potential & Lead{-}time & Fulfilment & Exchange & Political & DG & Criticality \\ \end{array} \begin{pmatrix} 1 & \frac{1}{5} & \frac{1}{6} & \frac{1}{6} & 2 & \frac{1}{4} & \frac{1}{7} & \frac{1}{4} \\ 5 & 1 & \frac{1}{6} & \frac{1}{6} & 8 & 8 & \frac{1}{2} & \frac{1}{4} \\ 6 & 6 & 1 & 1 & 7 & 7 & 7 & 7 \\ 6 & 6 & 1 & 1 & 7 & 7 & 4 & 7 \\ \frac{1}{5} & \frac{1}{8} & \frac{1}{7} & \frac{1}{7} & 1 & 1 & \frac{1}{7} & \frac{1}{7} \\ 4 & \frac{1}{8} & \frac{1}{7} & \frac{1}{7} & 1 & 1 & \frac{1}{7} & \frac{1}{7} \\ 7 & 2 & \frac{1}{7} & \frac{1}{4} & 7 & 7 & 1 & 1 \\ 4 & 4 & \frac{1}{7} & \frac{1}{7} & 7 & 7 & 1 & 1 \end{pmatrix}$$

$$A_{normalized} = \begin{array}{c} \\ Costs \\ Potential \\ Lead{-}time \\ Fulfilment \\ Exchange \\ Political \\ DG \\ Criticality \end{array} \begin{array}{cccccccc} Costs & Potential & Lead{-}time & Fulfilment & Exchange & Political & DG & Criticality \\ \end{array} \begin{pmatrix} 0.029 & 0.010 & 0.057 & 0.055 & 0.05 & 0.006 & 0.010 & 0.014 \\ 0.149 & 0.051 & 0.057 & 0.055 & 0.2 & 0.209 & 0.035 & 0.014 \\ 0.179 & 0.308 & 0.344 & 0.332 & 0.175 & 0.183 & 0.502 & 0.417 \\ 0.179 & 0.308 & 0.344 & 0.332 & 0.175 & 0.183 & 0.287 & 0.417 \\ 0.014 & 0.006 & 0.049 & 0.047 & 0.025 & 0.026 & 0.010 & 0.008 \\ 0.119 & 0.006 & 0.049 & 0.047 & 0.025 & 0.026 & 0.010 & 0.008 \\ 0.208 & 0.102 & 0.049 & 0.083 & 0.175 & 0.183 & 0.071 & 0.059 \\ 0.119 & 0.205 & 0.049 & 0.047 & 0.175 & 0.183 & 0.071 & 0.059 \end{pmatrix}$$

Step 2 w_{max}. $w_1 = .029$ for objective 1 (costs), $w_2 = .096$ for objective 2 (potential), $w_3 = .305$ for objective 3 (Lead-time), $w_4 = .278$ for objective 4 (fulfilment), $w_5 = .023$ for objective 5 (exchange rates), $w_6 = .036$

for objective 6 (Fufilment), $w_7 = .116$ for objective 7 (dangerous goods) and $w_8 = .113$ for objective 8 (criticality parts).

Checking for consistency
Step 1 Compute Aw^T.

$$Aw^T = \begin{bmatrix} 1 & \frac{1}{5} & \frac{1}{6} & \frac{1}{6} & 2 & \frac{1}{4} & \frac{1}{7} & \frac{1}{4} \\ 5 & 1 & \frac{1}{6} & \frac{1}{6} & 8 & 8 & \frac{1}{2} & \frac{1}{4} \\ 6 & 6 & 1 & 1 & 7 & 7 & 7 & 7 \\ 6 & 6 & 1 & 1 & 7 & 7 & 4 & 7 \\ \frac{1}{5} & \frac{1}{8} & \frac{1}{7} & \frac{1}{7} & 1 & 1 & \frac{1}{7} & \frac{1}{7} \\ 4 & \frac{1}{8} & \frac{1}{7} & \frac{1}{7} & 1 & 1 & \frac{1}{7} & \frac{1}{7} \\ 7 & 2 & \frac{1}{7} & \frac{1}{4} & 7 & 7 & 1 & 1 \\ 4 & 4 & \frac{1}{7} & \frac{1}{7} & 7 & 7 & 1 & 1 \end{bmatrix} \begin{bmatrix} 0.0293166 \\ 0.0966653 \\ 0.3051822 \\ 0.2782591 \\ 0.0234843 \\ 0.0365440 \\ 0.1166679 \\ 0.1138807 \end{bmatrix} = \begin{bmatrix} 0.247131376 \\ 0.907518245 \\ 3.373369963 \\ 3.023366284 \\ 0.203053946 \\ 0.305661921 \\ 1.162454882 \\ 1.238022211 \end{bmatrix}$$

Step 2 Compute consistency index (CI) as follows:

$$\frac{1}{8}\left[\frac{0.247131376}{0.0293166} + \frac{0.907518245}{0.0966653} + \frac{3.373369963}{0.3051822} + \frac{3.023366284}{0.2782591} + \frac{0.203053946}{0.0234843} + \frac{0.305661921}{0.0365440} + \frac{1.162454882}{0.1166679} + \frac{1.238022211}{0.1138807}\right] = 9.697 \quad (16)$$

CI $= \frac{9.697-n}{n-1} = \frac{9.697-8}{7} = 0.242545503$

Step 3 In our AHP the $\frac{CI}{RI}$ ratio is 0.16727276

Optimal alternative:
Melbourne, Australia
Distribution center
APAC flow
WP&P

B.15.3 Weight of objectives by Florian Kriz

Prioritization criteria																
COSTS	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	POTENTIAL
COSTS	8	7	6	5	4	3	2	1	2	3	4	5	**6**	7	8	LEAD-TIME
COSTS	8	7	6	5	4	3	2	1	2	3	4	5	**6**	7	8	ORDER FULFILLMENT
COSTS	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	EXCHANGE RATE STABILITY
COSTS	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	POLITICAL RISK INDEX
COSTS	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	DANGEROUS GOODS
COSTS	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	CRITICALITY PARTS
POTENTIAL	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	LEAD-TIME
POTENTIAL	8	7	6	**5**	4	3	2	1	2	3	4	5	6	7	8	ORDER FULFILLMENT
POTENTIAL	8	7	**6**	5	4	3	2	1	2	3	4	5	6	7	8	EXCHANGE RATE STABILITY
POTENTIAL	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	POLITICAL RISK INDEX
POTENTIAL	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	DANGEROUS GOODS
POTENTIAL	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	CRITICALITY PARTS
LEAD-TIME	8	7	6	5	4	3	2	1	2	3	4	5	**6**	7	8	ORDER FULFILLMENT
LEAD-TIME	8	7	**6**	5	4	3	2	1	2	3	4	5	6	7	8	EXCHANGE RATE STABILITY
LEAD-TIME	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	POLITICAL RISK INDEX
LEAD-TIME	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	DANGEROUS GOODS
LEAD-TIME	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	CRITICALITY PARTS
ORDER FULFILLMENT	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	EXCHANGE RATE STABILITY
ORDER FULFILLMENT	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	POLITICAL RISK INDEX
ORDER FULFILLMENT	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	DANGEROUS GOODS
ORDER FULFILLMENT	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	CRITICALITY PARTS
EXCHANGE RATE STABILITY	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	POLITICAL RISK INDEX
EXCHANGE RATE STABILITY	8	7	6	5	4	3	2	1	2	3	4	5	**6**	7	8	DANGEROUS GOODS
EXCHANGE RATE STABILITY	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	CRITICALITY PARTS
POLITICAL RISK INDEX	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	DANGEROUS GOODS
POLITICAL RISK INDEX	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	CRITICALITY PARTS
DANGEROUS GOODS	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	CRITICALITY PARTS

Table 41: Prioritization Florian Kriz - Manager Product Marketing

Finding w_{max}.

Step 1 A and A_{norm}.

$$\text{When A} = \begin{array}{r} \\ Costs \\ Potential \\ Lead{-}time \\ Fulfilment \\ Exchange \\ Political \\ DG \\ Criticality \end{array} \begin{array}{cccccccc} Costs & Potential & Lead{-}time & Fulfilment & Exchange & Political & DG & Criticality \end{array} \left(\begin{array}{cccccccc} 1 & \frac{1}{7} & \frac{1}{6} & \frac{1}{6} & 1 & 1 & 1 & \frac{1}{7} \\ 7 & 1 & 7 & 5 & 6 & 1 & 1 & \frac{1}{7} \\ 6 & \frac{1}{7} & 1 & \frac{1}{6} & 6 & 1 & 1 & \frac{1}{7} \\ 6 & \frac{1}{5} & 6 & 1 & 7 & 1 & 1 & \frac{1}{7} \\ 1 & \frac{1}{6} & \frac{1}{6} & \frac{1}{7} & 1 & 1 & \frac{1}{6} & \frac{1}{7} \\ 1 & 1 & 1 & 1 & 1 & 1 & 7 & \frac{1}{7} \\ 1 & 1 & 1 & 1 & 6 & \frac{1}{7} & 1 & \frac{1}{7} \\ 7 & 7 & 7 & 7 & 7 & 7 & 7 & 1 \end{array} \right)$$

$$A_{normalized} = \begin{array}{r} \\ Costs \\ Potential \\ Lead{-}time \\ Fulfilment \\ Exchange \\ Political \\ DG \\ Criticality \end{array} \begin{array}{cccccccc} Costs & Potential & Lead{-}time & Fulfilment & Exchange & Political & DG & Criticality \end{array} \left(\begin{array}{cccccccc} 0.033 & 0.013 & 0.007 & 0.010 & 0.028 & 0.076 & 0.052 & 0.071 \\ 0.233 & 0.093 & 0.3 & 0.323 & 0.171 & 0.076 & 0.052 & 0.071 \\ 0.2 & 0.013 & 0.042 & 0.010 & 0.171 & 0.076 & 0.052 & 0.071 \\ 0.2 & 0.018 & 0.257 & 0.064 & 0.2 & 0.076 & 0.052 & 0.071 \\ 0.033 & 0.0156 & 0.007 & 0.009 & 0.0285 & 0.076 & 0.008 & 0.071 \\ 0.033 & 0.093 & 0.0428 & 0.0646 & 0.0285 & 0.076 & 0.365 & 0.071 \\ 0.033 & 0.093 & 0.042 & 0.064 & 0.171 & 0.010 & 0.052 & 0.071 \\ 0.233 & 0.657 & 0.3 & 0.452 & 0.2 & 0.532 & 0.365 & 0.5 \end{array} \right)$$

Step 2 w_{max}. $w_1 = .036$ for objective 1 (costs), $w_2 = .165$ for objective 2 (potential), $w_3 = .079$ for objective 3 (Lead-time), $w_4 = .117$ for objective 4 (fulfilment), $w_5 = .031$ for objective 5 (exchange rates), $w_6 = .097$

for objective 6 (Fufilment), $w_7 = .067$ for objective 7 (dangerous goods) and $w_8 = .405$ for objective 8 (criticality parts).

Checking for consistency
Step 1 Compute Aw^T.

$$Aw^T = \begin{bmatrix} 1 & \frac{1}{7} & \frac{1}{6} & \frac{1}{6} & 1 & 1 & 1 & \frac{1}{7} \\ 7 & 1 & 7 & 5 & 6 & 1 & 1 & \frac{1}{7} \\ 6 & \frac{1}{7} & 1 & \frac{1}{6} & 6 & 1 & 1 & \frac{1}{7} \\ 6 & \frac{1}{5} & 6 & 1 & 7 & 1 & 1 & \frac{1}{7} \\ 1 & \frac{1}{6} & \frac{1}{6} & \frac{1}{7} & 1 & 1 & \frac{1}{6} & \frac{1}{7} \\ 1 & 1 & 1 & 1 & 1 & 1 & 7 & \frac{1}{7} \\ 1 & 1 & 1 & 1 & 6 & \frac{1}{7} & 1 & \frac{1}{7} \\ 7 & 7 & 7 & 7 & 7 & 7 & 7 & 1 \end{bmatrix} \begin{bmatrix} 0.0366146 \\ 0.1651755 \\ 0.0797694 \\ 0.1175279 \\ 0.0312669 \\ 0.0969982 \\ 0.0675728 \\ 0.4050746 \end{bmatrix} = \begin{bmatrix} 0.34679978 \\ 1.977543508 \\ 0.752682175 \\ 1.290174596 \\ 0.291623601 \\ 1.058229814 \\ 0.725986509 \\ 4.569552102 \end{bmatrix}$$

Step 2 Compute consistency index (CI) as follows:

$$\frac{1}{8}\left[\frac{0.34679978}{0.0366146} + \frac{1.977543508}{0.1651755} + \frac{0.752682175}{0.0797694} + \frac{1.290174596}{0.1175279} + \frac{0.291623601}{0.0312669} + \frac{1.058229814}{0.0969982} + \frac{0.725986509}{0.0675728} + \frac{4.569552102}{0.4050746}\right] = 10.5148 \tag{17}$$

CI $= \frac{10.5148-n}{n-1} = \frac{10.5148-8}{7} = 0.35925$

Step 3 In our AHP the $\frac{CI}{RI}$ ratio is 0.24

Optimal alternative:
Melbourne, Australia
Distribution center
APAC flow
WP&P